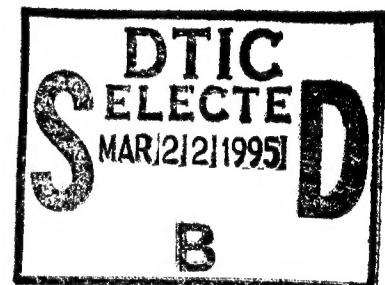


Marine Physical Laboratory

Ambient Noise Vertical and Horizontal Directionality During SWellEX-1

**Gerald D'Spain, Tony Richardson,
William S. Hodgkiss, and Lewis Berger**

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ABSTRACT

SWellEx-1 (Shallow Water evaluation cell Experiment #1) was carried out in August 1993 west of Point Loma in approximately 200 m water. During SWellEx-1, a MPL 48-element vertical array was deployed from the R/P FLIP. In addition, the McDonnell-Douglas two-dimensional seafloor array (USTS) was deployed nearby and cabled back to FLIP for data recording. As well as along-slope and cross-slope source tow events, several days of ambient noise data were collected with both arrays. Shipping noise varied substantially during this period due to fluctuations in traffic patterns. The focus of this paper is on the temporal evolution of ambient noise vertical and horizontal directionality during SWellEx-1. For selected data segments, dominant shipping sources will be identified geographically and the observed vertical and horizontal directionality related to source-array propagation characteristics. [Work supported by ONR, Code 321 and NRL, Code 7120].

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**Ambient Noise Vertical
and Horizontal Directionality
during SWELLEx-1**

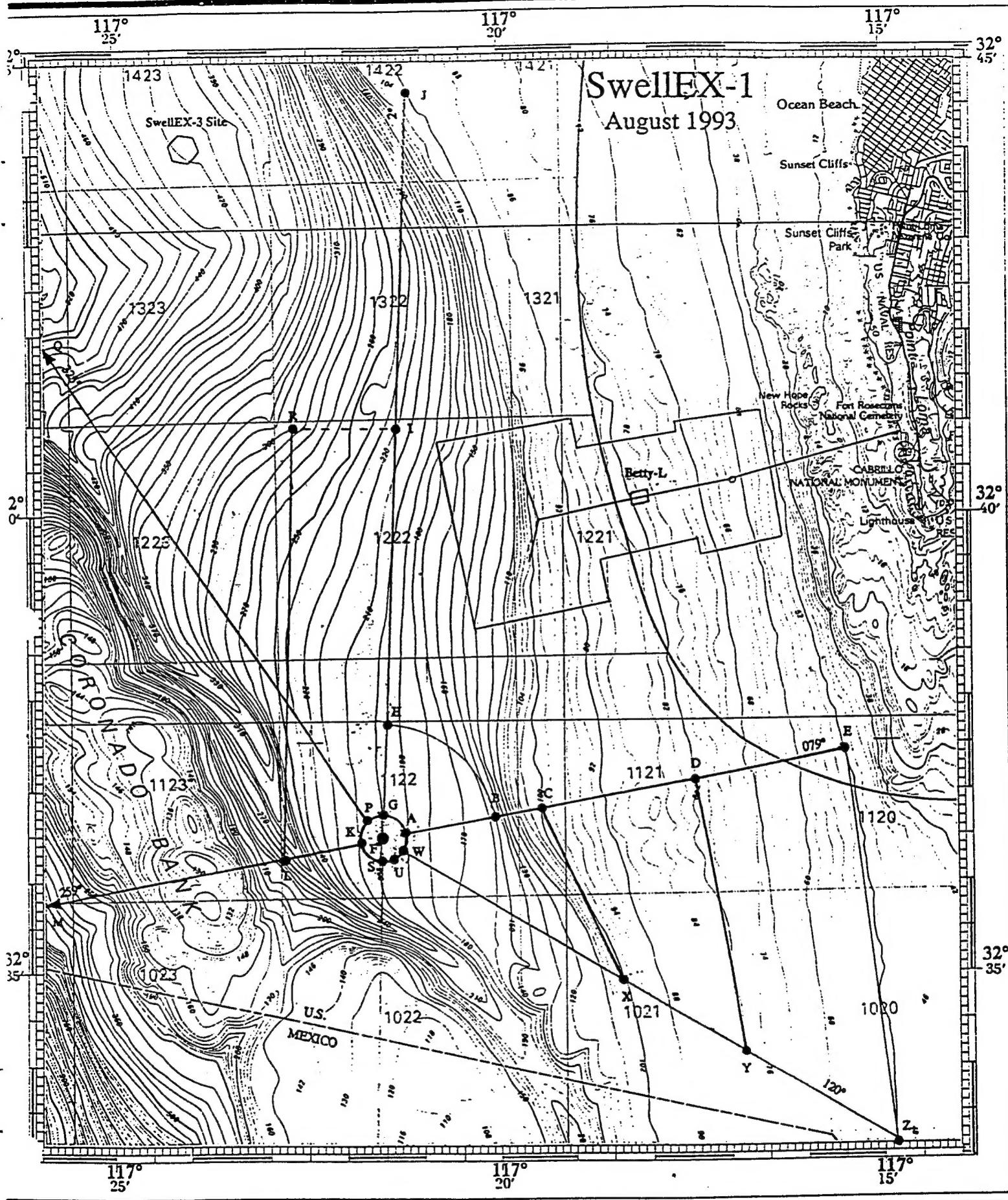
Gerald D'Spain, Tony Richardson,
Bill Hodgkiss, and Lewis Berger

Marine Physical Laboratory of the
Scripps Institution of Oceanography
University of California, San Diego
San Diego, California

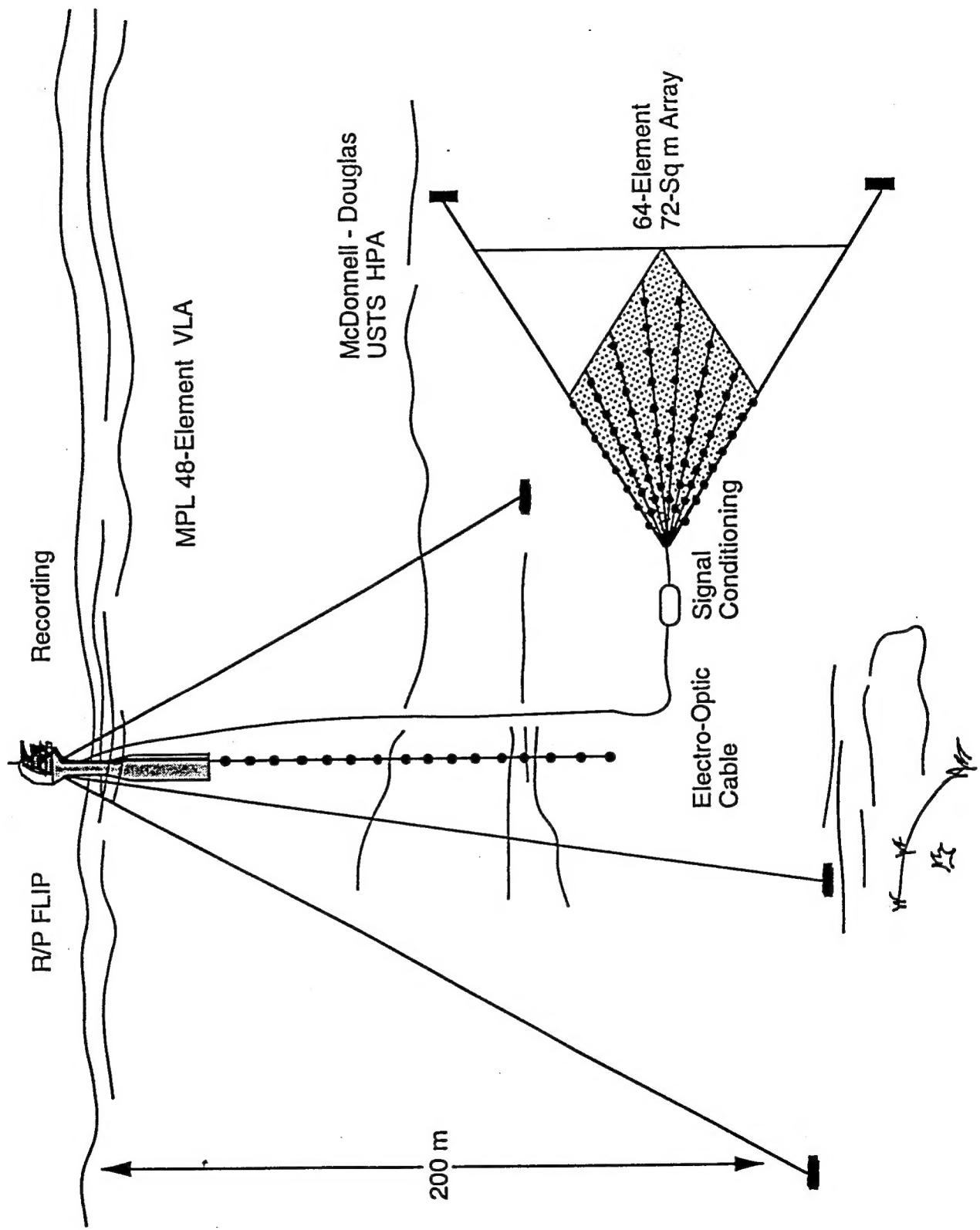
OBJECTIVE:

Examine some of the features in the temporal
evolution of the vertical and horizontal
directionality of the background sound field.

SwellEX-1
August 1993



SWELLEx - 1 Arrays



6 HOUR PLOTS

Single Element Gram

Horizontal Directionality

@ 400-450 Hz

Vertical Directionality

@ 400-450 Hz

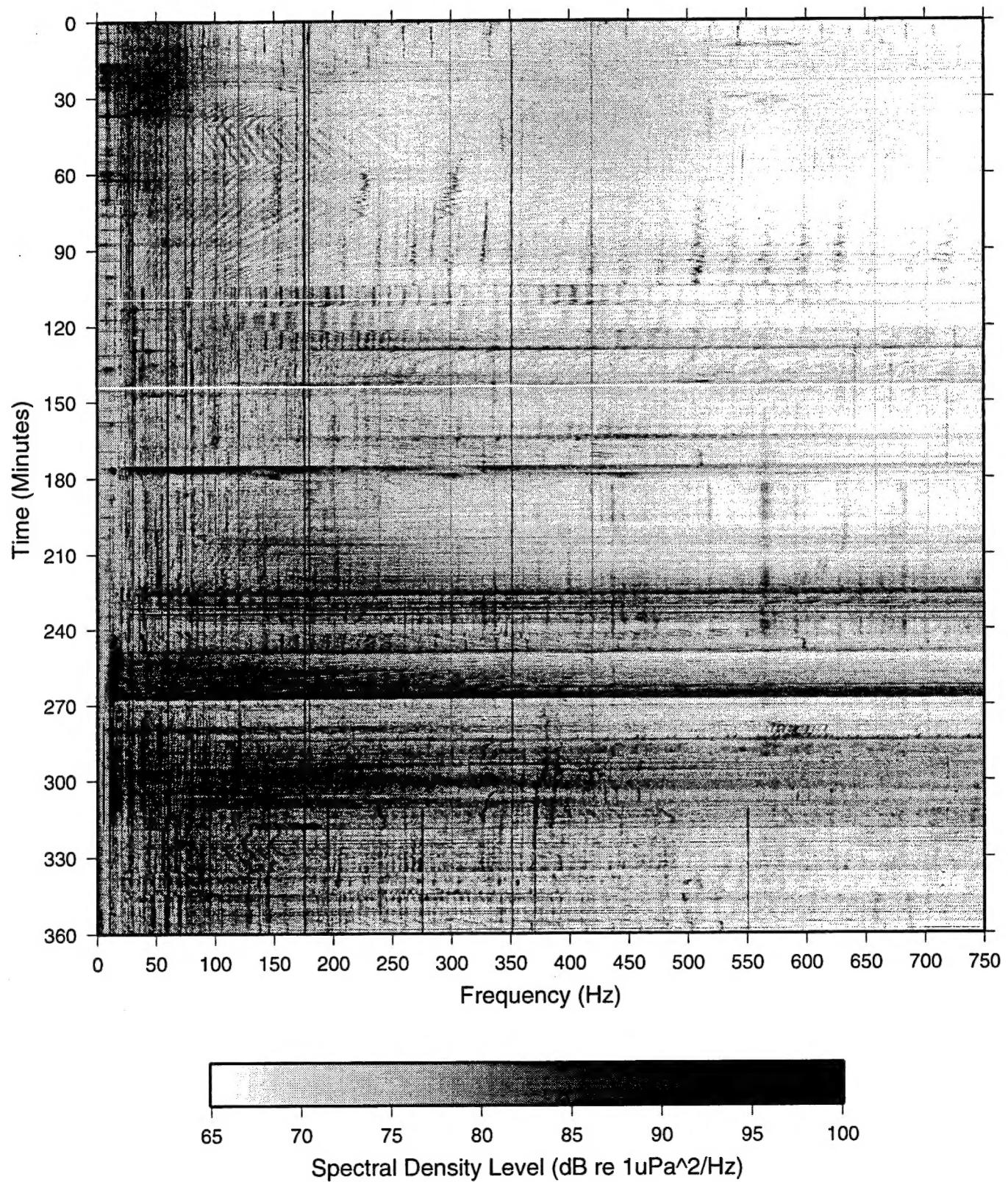
6 Hour Plots - Some Comments

1. "Calibration" signals generated by R/P FLIP occur at 175 and 350 Hz.
2. The towed source, programmed to broadcast tones at 70, 95, 145, 195, 275, 370, and 550 Hz, is turned on about 310 min after start of the data shown in the plots.
3. Daybreak occurs about 1 hour after the start of the data in the plots.
4. Before daybreak, compared to after daybreak:
 - a. changes in spectral level occur more slowly with time, as do the changes in beam levels between 400 and 450 Hz;
 - b. the distribution of energy with azimuth in the 400 - 450 Hz band is more diffuse spatially;
 - c. the distribution of energy in the vertical (400 - 450 Hz band) is more concentrated in the horizontal direction (i.e., no "noise notch" in the horizontal direction exists).
5. These properties of the energy between 400 - 450 Hz observed before daybreak are due to the presence of two diffuse "clouds" of spectral energy occurring between 300 - 500 Hz, and from 600 to 700 Hz. This energy is coming predominantly from the east and southeast, with another component coming in from slightly west of north, and also in the horizontal direction. The clouds disappear shortly after sunrise.
6. After daybreak, ambient noise levels appear to be dominated by discrete shipping sources.
7. Large, sudden increases in the single-element, broadband spectral levels correspond to rapid changes in azimuth of spatially concentrated sources and to increases in higher-vertical-angle beam levels.

USTS Array Single Element Gram

8/17/93 04:45:00 PDT

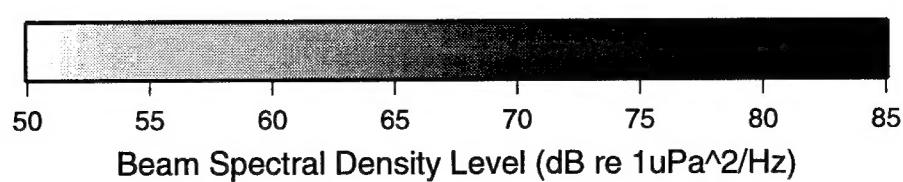
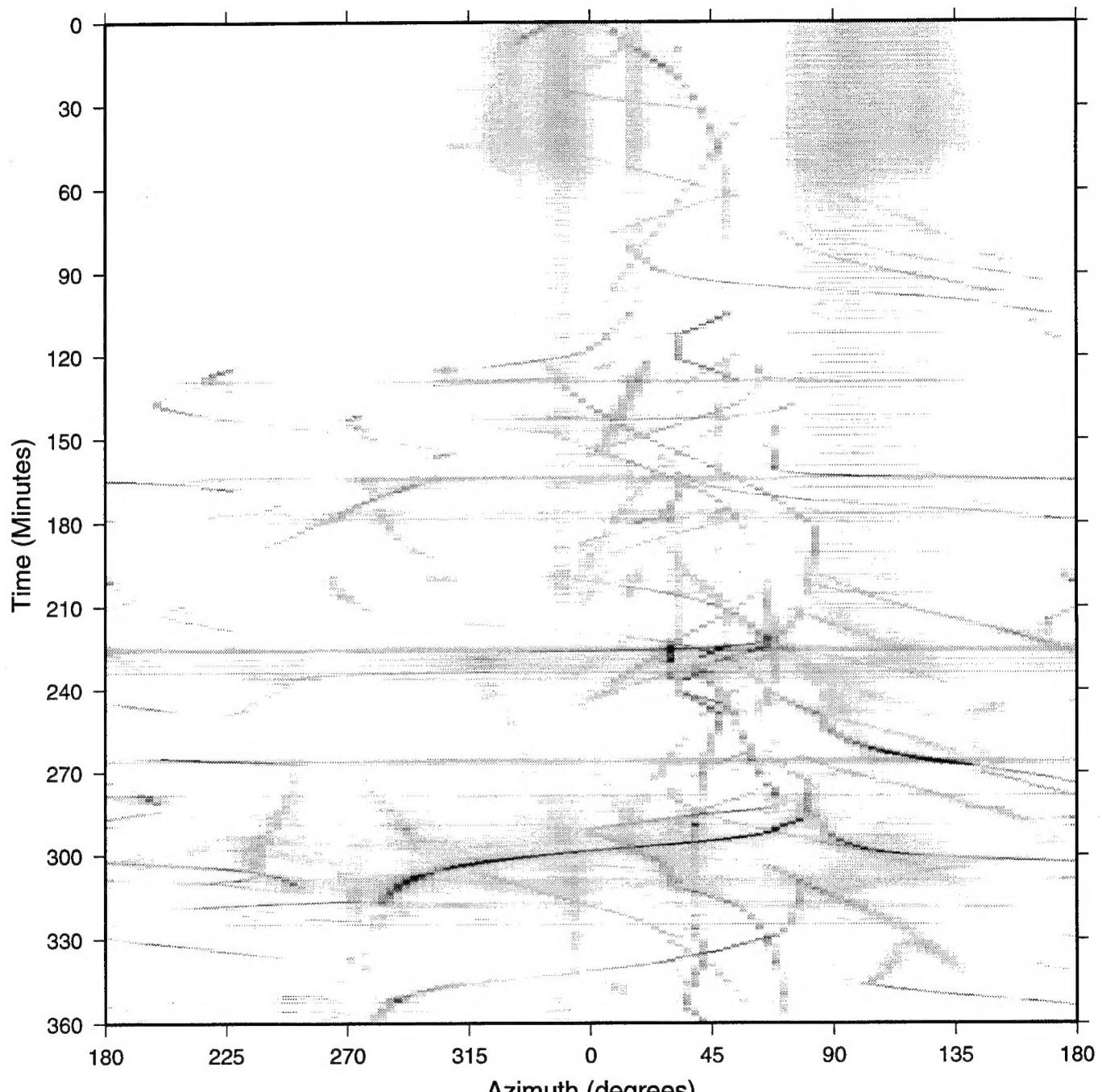
Element 46 Fs=1978.744



USTS Adaptive WNC Beamformer Response

8/17/93 04:45:00 PDT

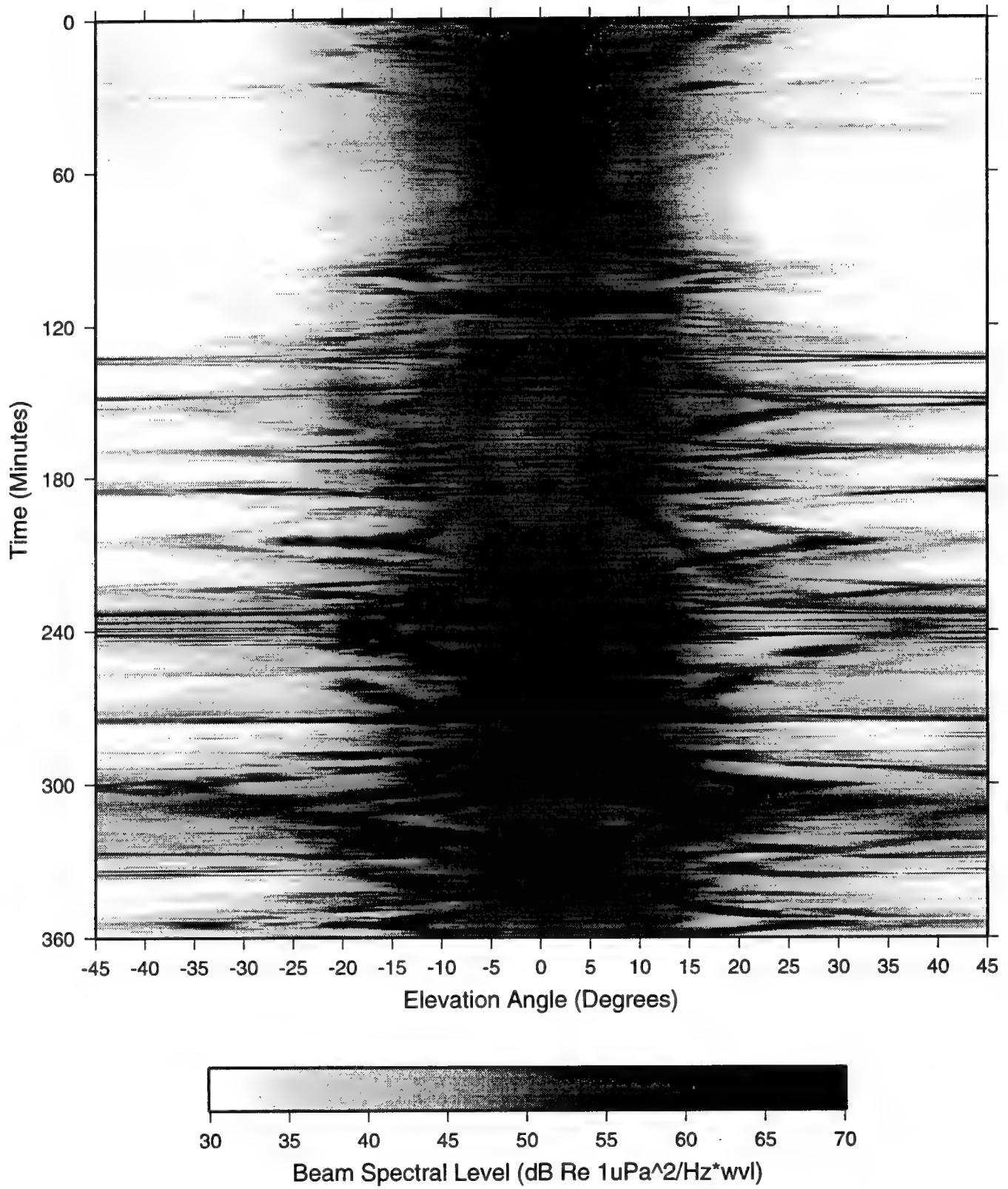
El. = 12; Broadband Response (f=400:450); N = 72



SRP Beamformer Response

JD 229 Time 04:45 PDT

Frequency Band 400 - 450 Hz



1.5 HOUR PLOTS

Single Element Gram

Horizontal Directionality

@ 400-450 Hz

Vertical Directionality

@ 400-450 Hz

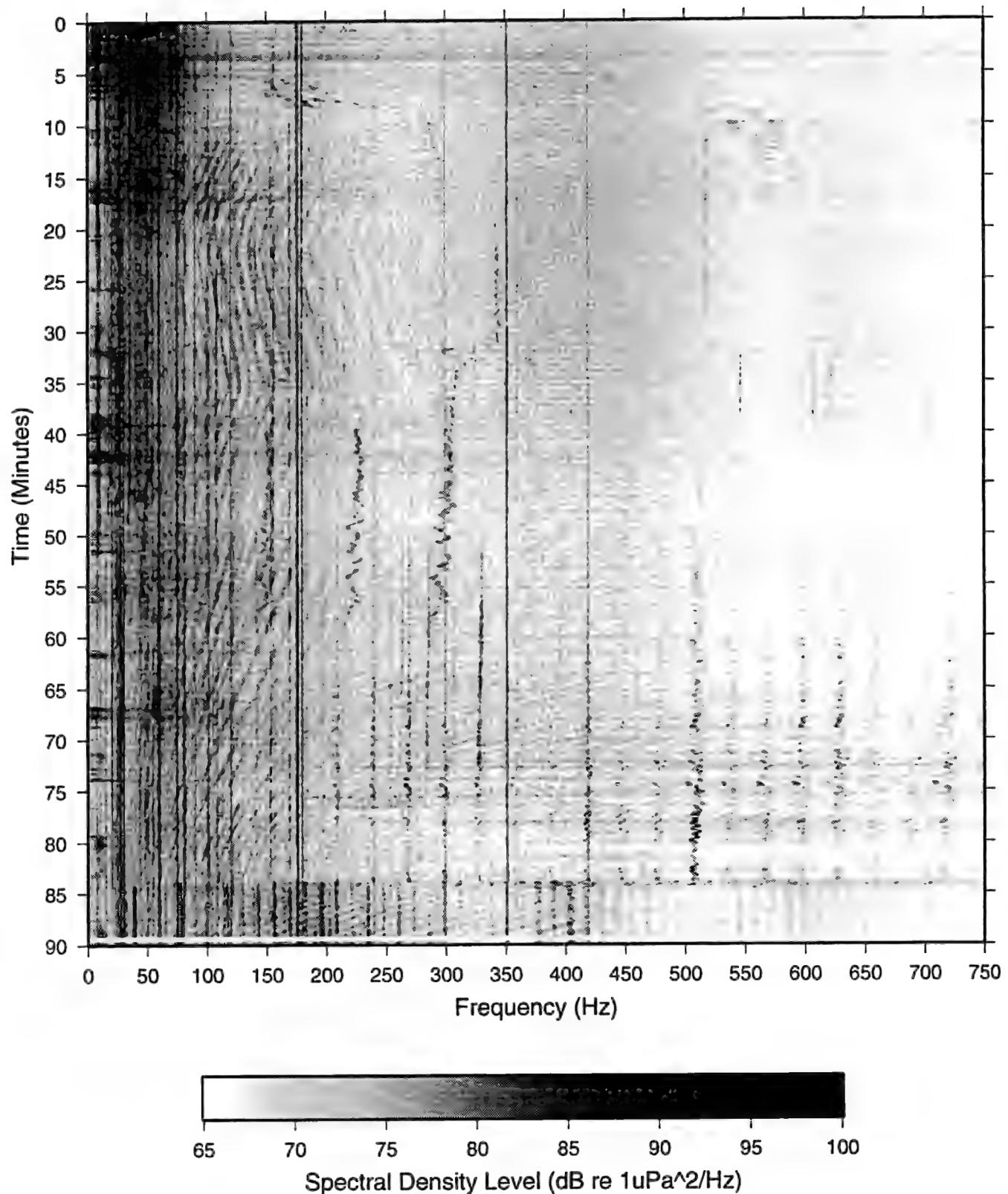
1.5 Hour Plots - Some Comments

1. The start of these data, at 05:05 PDT, occurs 20 min after the start of the data in the 6-hour plots.
2. The two "clouds" of spectral energy centered at 450 and 650 Hz are composed of bands of high and low levels that alternate periodically in time. Because the 650 Hz energy shows the same alternating pattern as the 450 Hz energy, both are probably due to the same source. The time interval between high levels increases with the approach of daybreak, and thereafter until the signals disappear altogether.
3. The broadband spectral levels below 70 Hz decrease with time over the 1.5 hour period.

USTS Array Single Element Gram

8/17/93 05:05:00 PDT

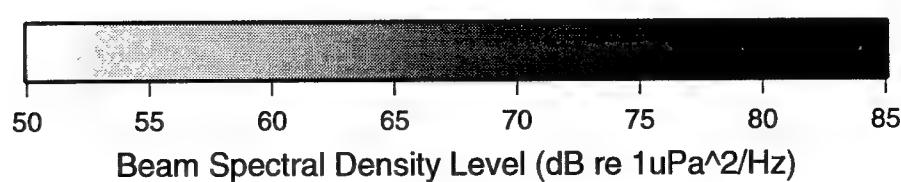
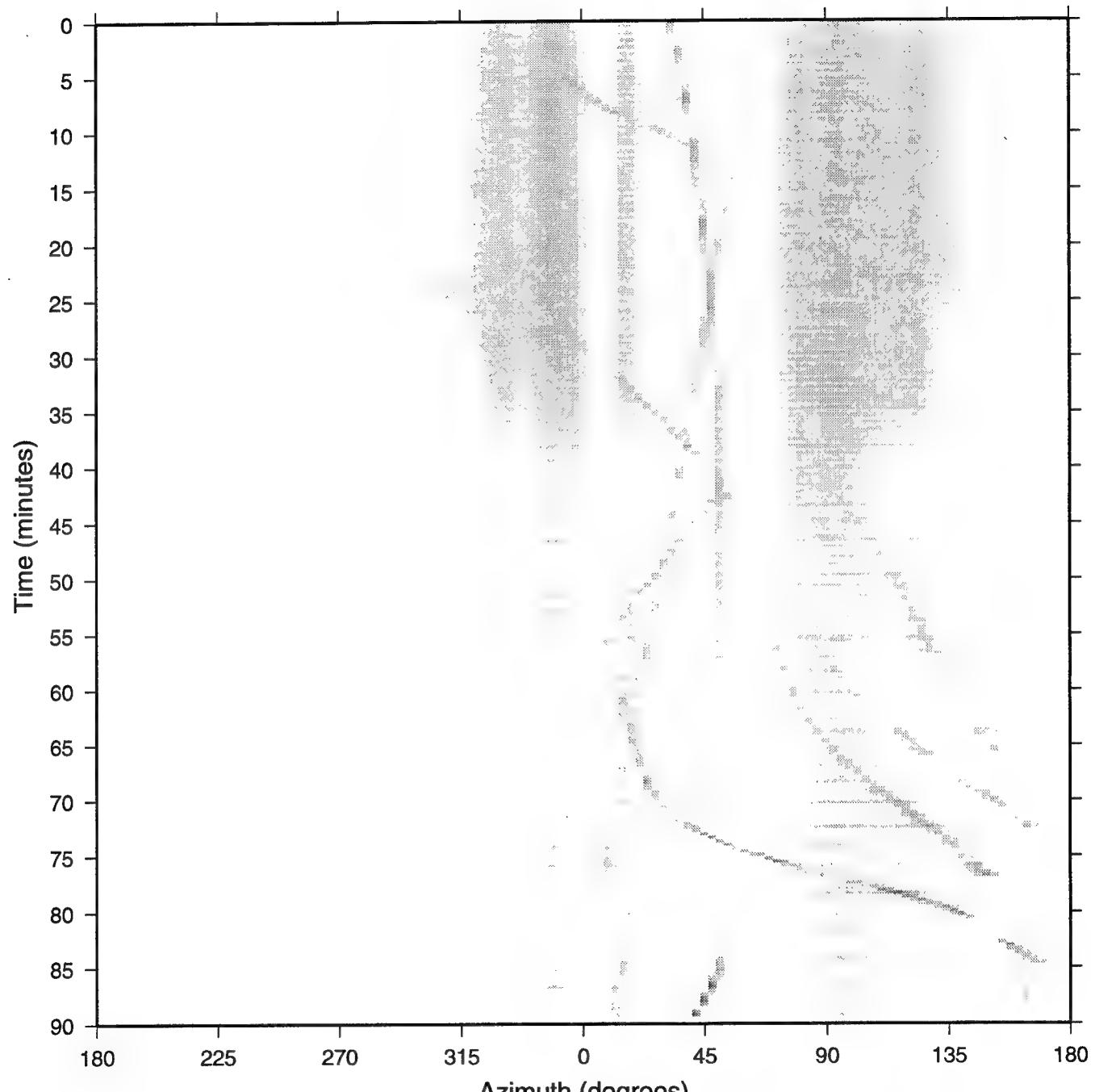
Element 46 Fs=1978.744



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

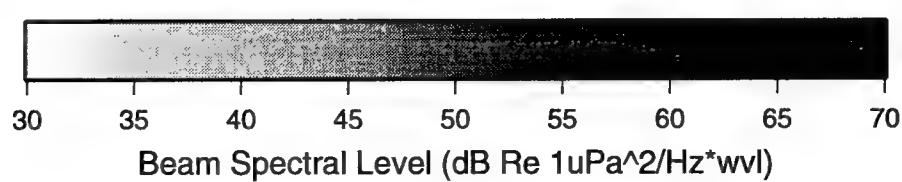
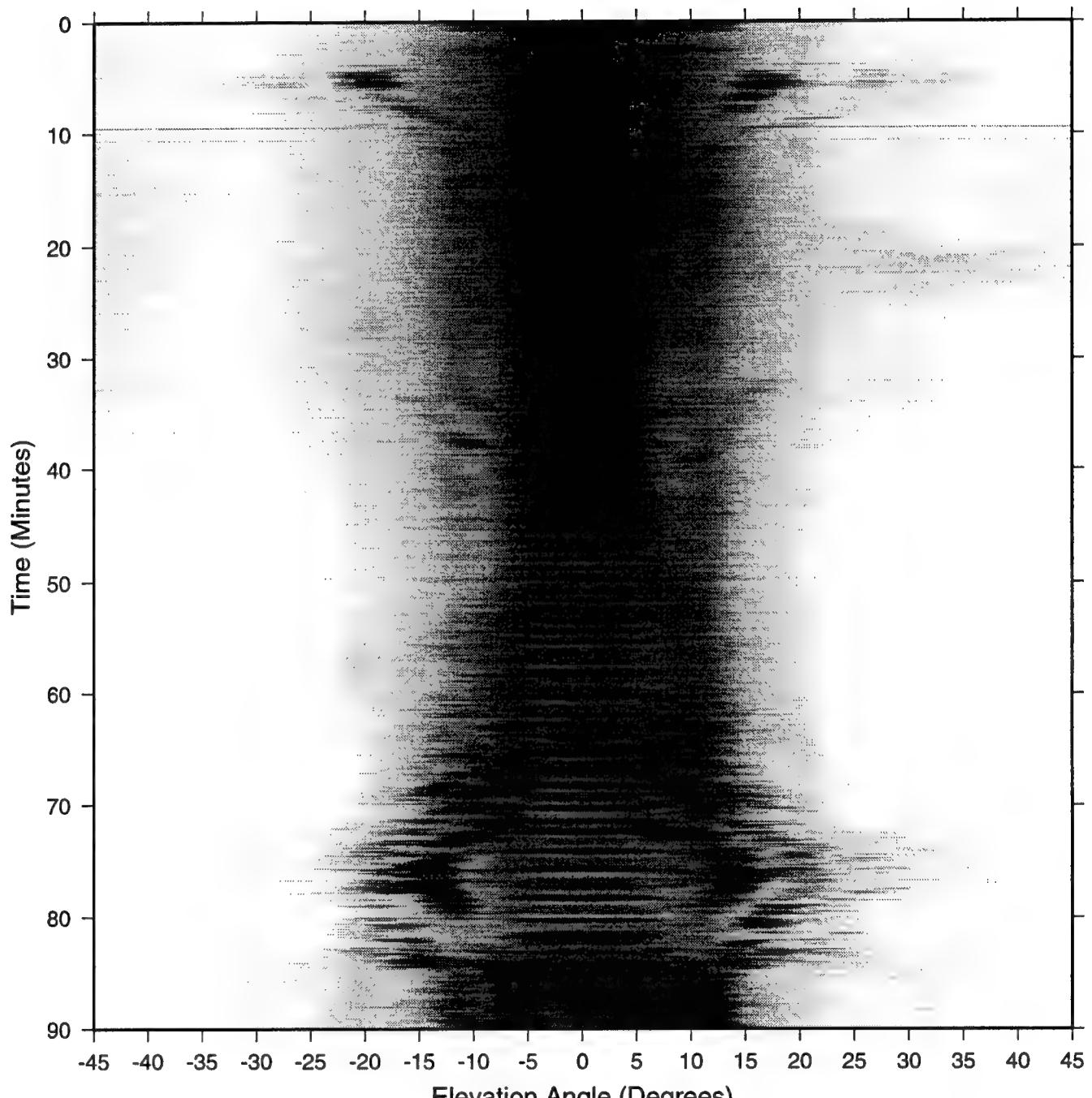
El. = 12; Broadband Response (f=400:450); N = 72



SRP Beamformer Response

JD 229 Time 05:05 PDT

Frequency Band 400 - 450 Hz



15 MINUTE PLOTS

Single Element Gram

Horizontal Directionality

@ 400-450 Hz

Vertical Directionality

@ 400-450 Hz

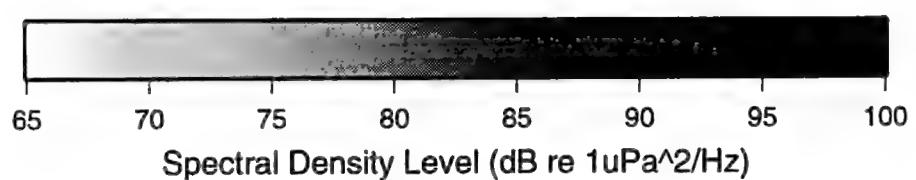
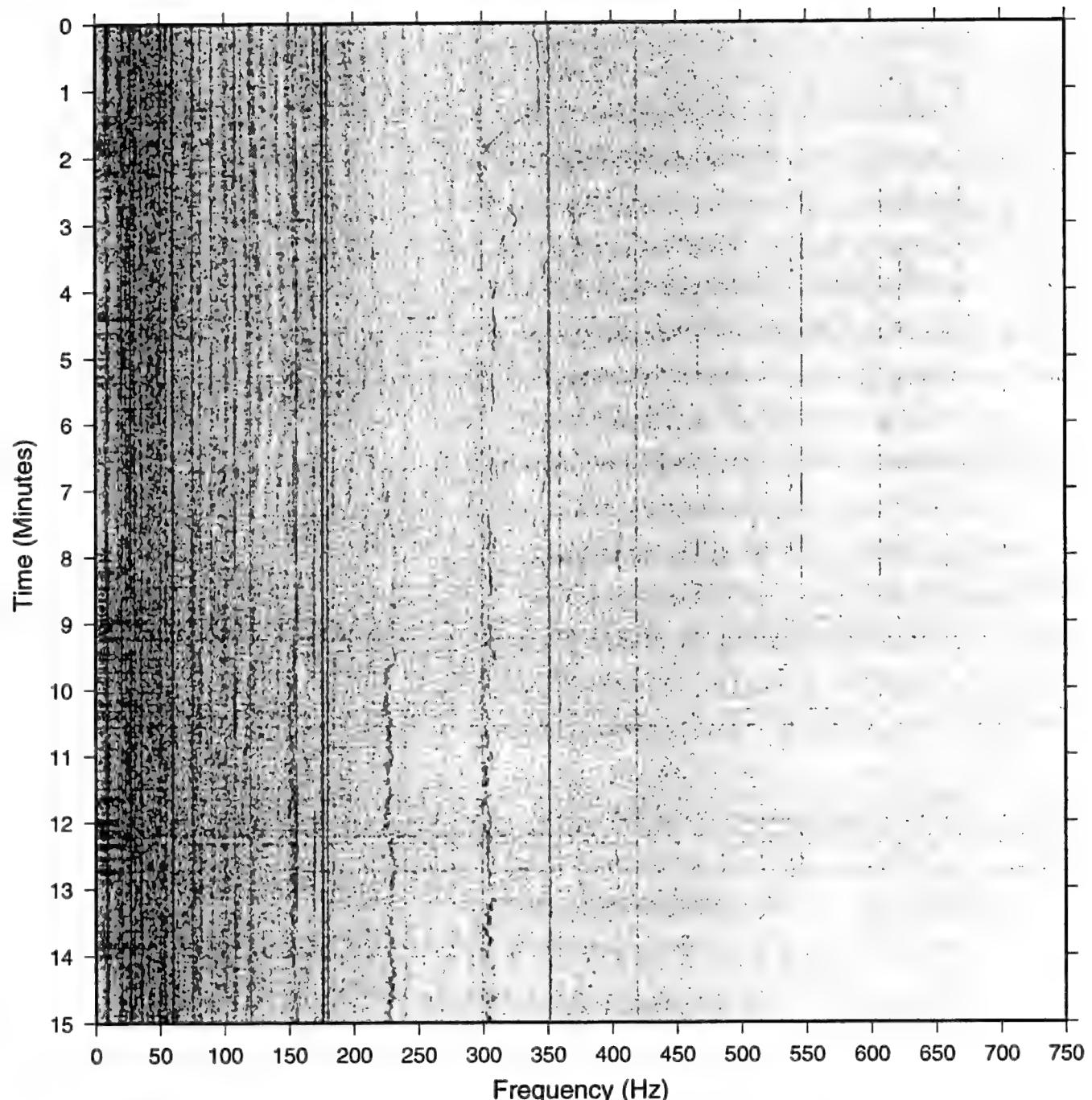
15 Min Plots - Some Comments

1. The data in these plots start at 05:35 PDT, which is 30 minutes after the start of the data in the 1.5 hour plots.
2. The difference in the high and low levels in the spectral "clouds" centered at 450 and 650 Hz is 3 - 6 dB.
3. The times of high levels in the 400 - 450 Hz band in the northward direction do not necessarily correspond to the times of high levels in the east and southeast directions, particularly as the period between the high levels increases.

USTS Array Single Element Gram

8/17/93 05:35:00 PDT

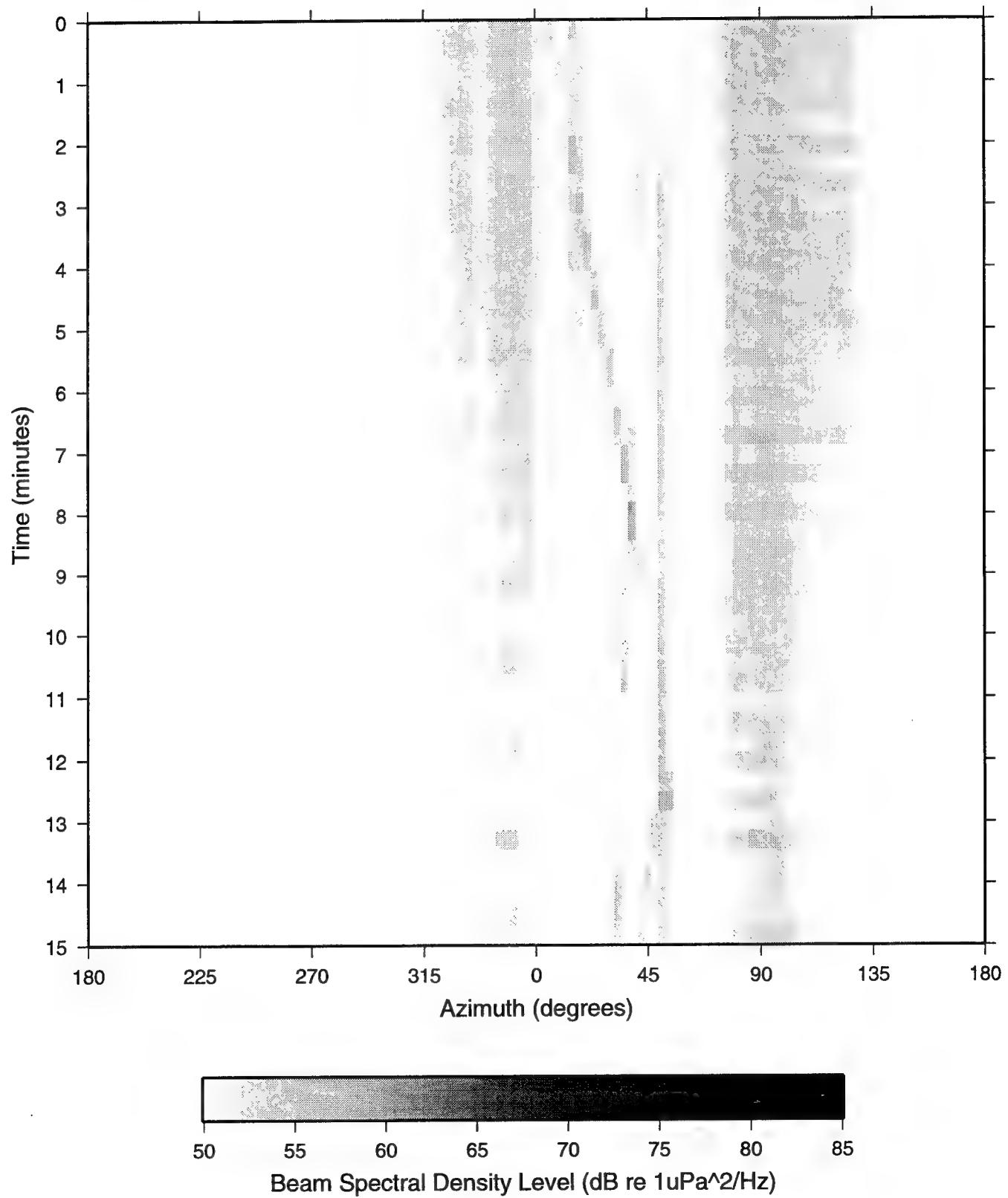
Element 46 Fs=1978.744



USTS Adaptive WNC Beamformer Response

8/17/93 05:35:00 PDT

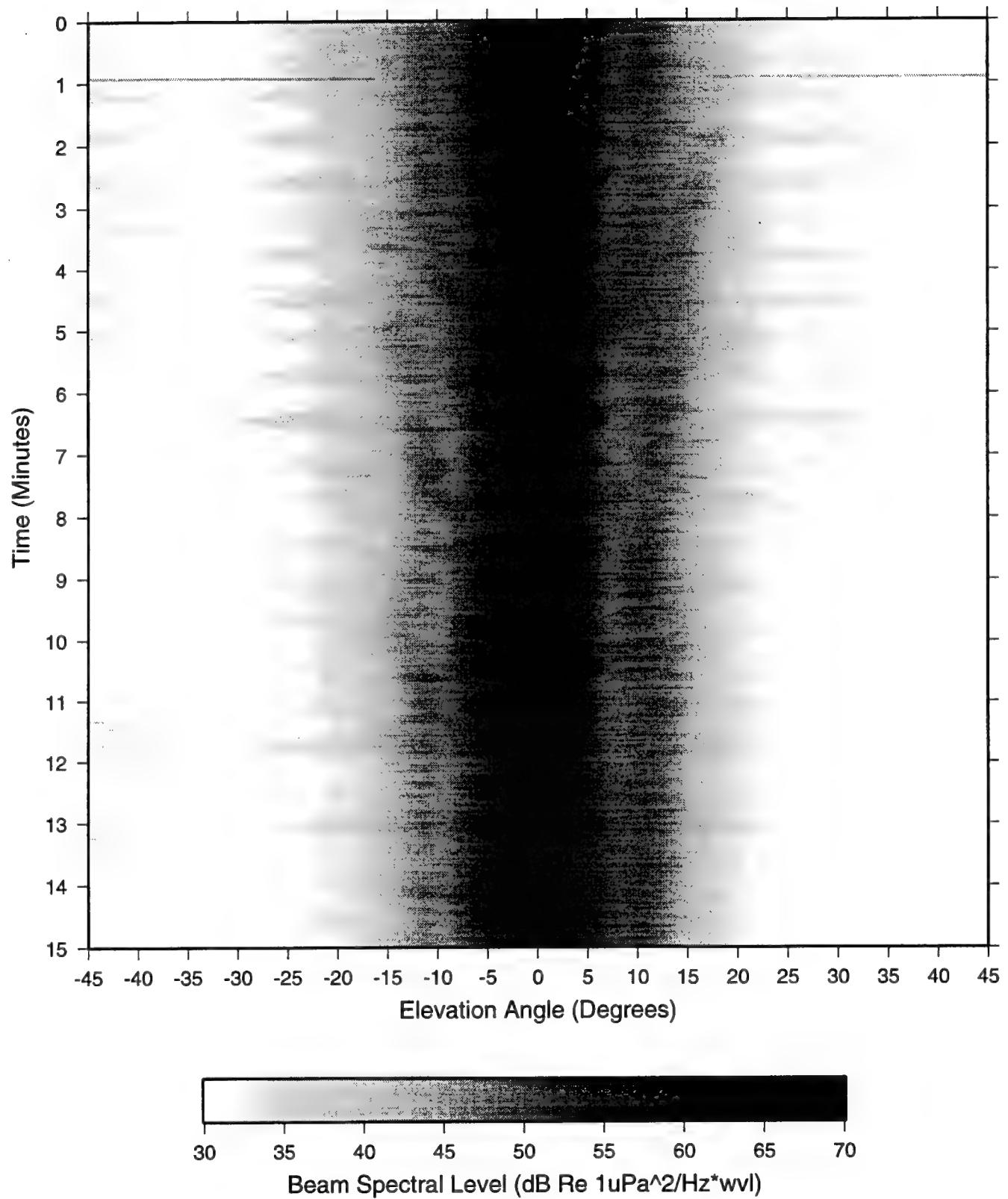
El. = 12; Broadband Response (f=400:450); N = 72



SRP Beamformer Response

JD 229 Time 05:35 PDT

Frequency Band 400 - 450 Hz

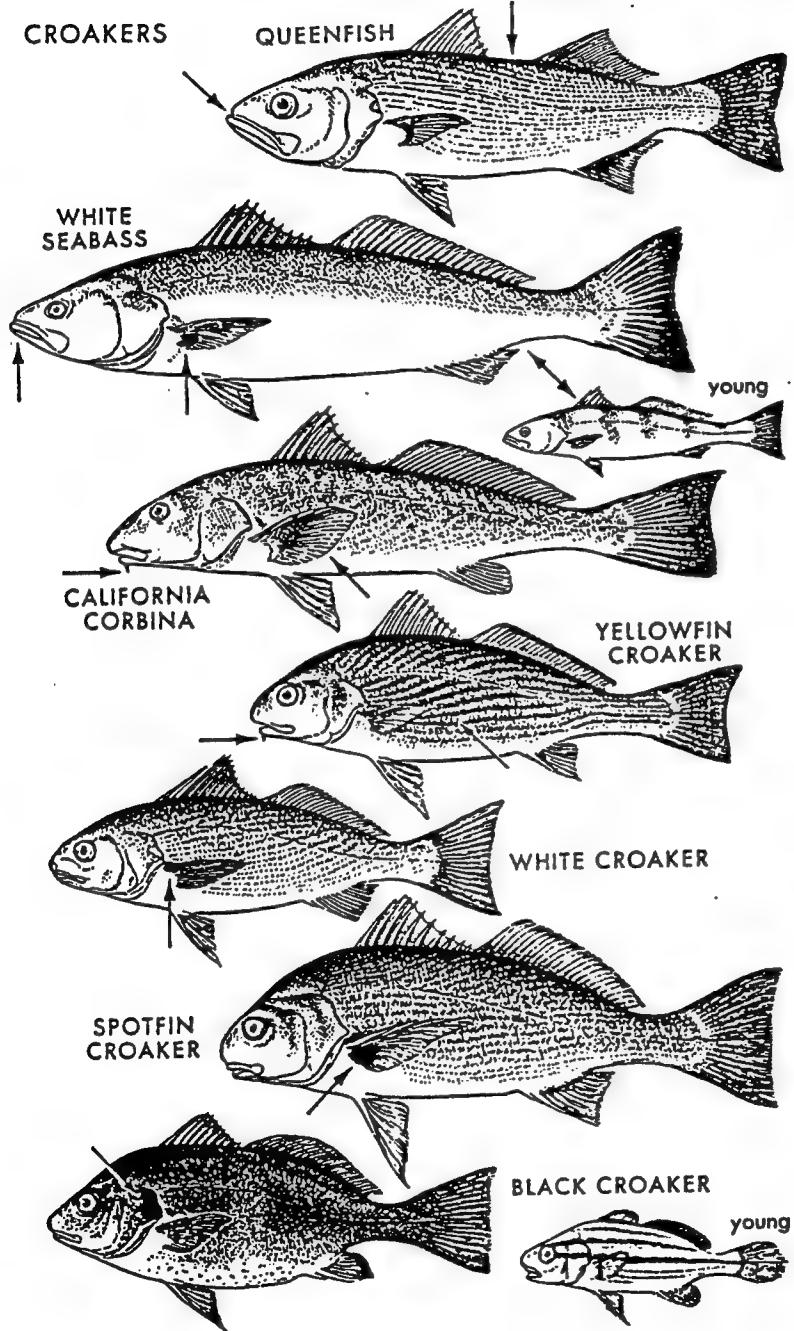


Comments on the 450 and 650 Hz Spectral "Clouds"

1. The properties of these "clouds", i.e., their spectral content (300 - 500 Hz and 600 - 700 Hz), their azimuthal directionality (coming mostly from areas where the water depths are less than 50 m and where sandy ocean bottoms exist), their vertical directionality (arriving in the horizontal direction due to downslope conversion), their frequency-of-occurrence (15 - 30 sec of high levels interspersed with half-minute to a minute-and-a-half periods of lower levels), and their diurnal variation (occurring at night and disappearing shortly after sunrise), correspond to the characteristics seen in year-long, single-hydrophone measurements made in the early 1960's at the NEL tower (located in 60 ft of water just west of Mission Beach, San Diego) [G. A. Clapp, NEL Tech Mem 1027, 1966]. In the 1966 report, these signals were attributed to sounds made by fish of the croaker family. Because they migrate in schools into deeper water at night in order to feed on plankton and because they are so abundant off the Southern California coast, the queenfish (shown at the top of the following page) are the likely source of the signals [W. C. Cummings, private communication, R. Rosenblatt, private communication].
2. These biological signals appear as "clouds" in another sense. That is, by raising appreciably the night-time ambient noise levels over a broad frequency range, they can have a significant impact on the ability to detect quiet targets of interest that operate at night.

"Croak, Croak"

33



1.5 HOUR BEAM GRAMS

8 Azimuthal Directions

1.5 Hour Beam Grams; 8 Azim. Directions - Some Comments

1. The 1.5-hour time period covered by these plots is the same period, i.e., 05:05 - 06:35 PDT, discussed previously.

2. The directions of the 8 azimuthal beams were chosen because:

0 deg : due north, looking in a direction of very gradual shoaling waters;

35 deg : northeast, towards the Betty-L barge, a large platform being used during SWellEx-1 in the construction of the extension to the city's sewer outfall pipe;

79 deg : eastward, upslope, and approximately perpendicular to the bottom bathymetric contours;

120 deg : southeast, southward of the opening to San Diego Harbor;

180 deg : due south, across the shallow part of the southward extension of the Coronado Bank;

219 deg : southwest, looking through a narrow "valley" separating two major ridges of the Coronado Bank;

259 deg : westward, across the Coronado Bank, approximately perpendicular to the bottom bathymetric contours;

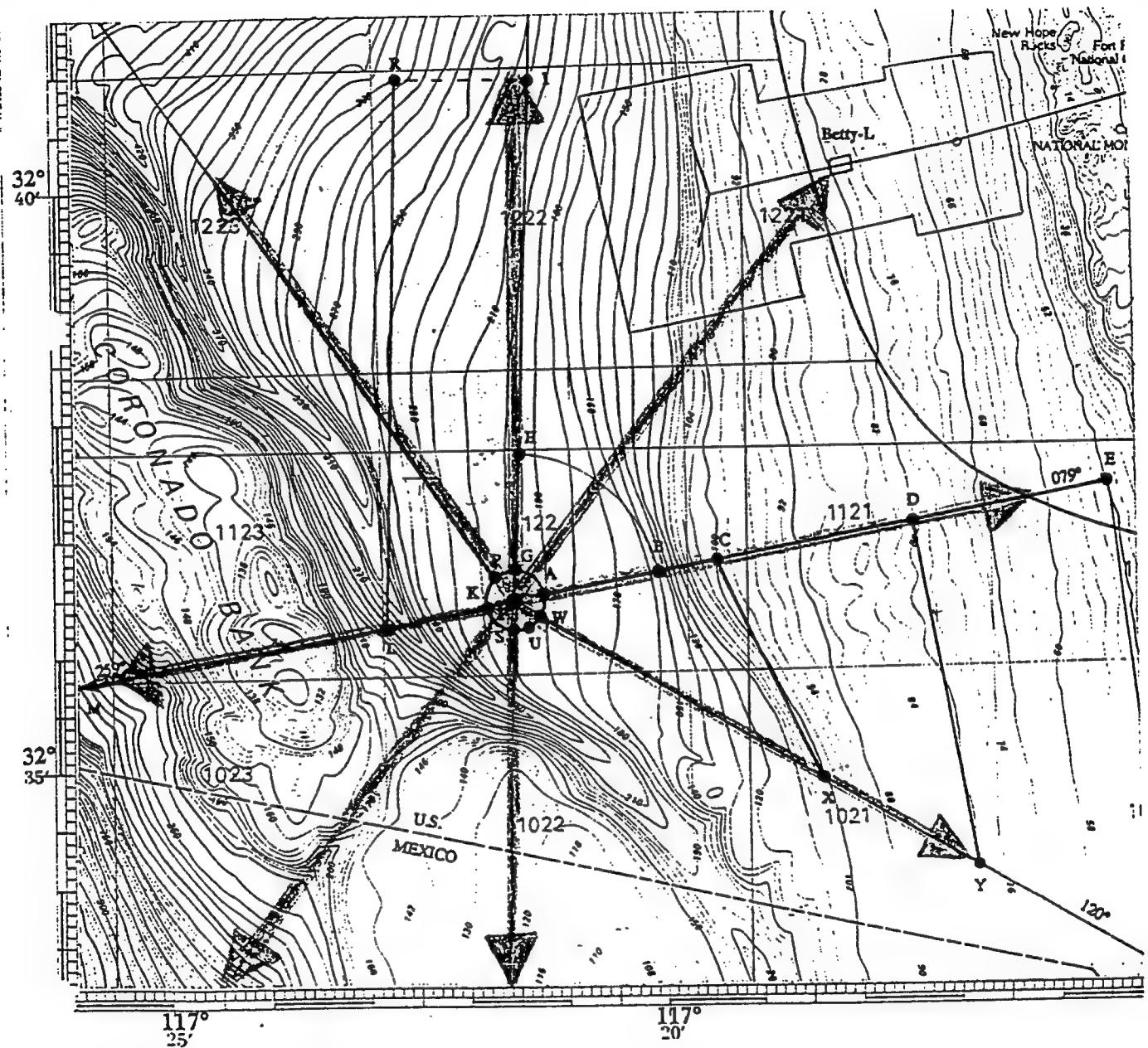
325 deg : northwest, looking down a "ravine" towards the heavy shipping area west of Long Beach and Los Angeles Harbors.

3. Beam levels change slowly over time except for the occurrence of broadband, high level, rapid, short duration changes associated with the transit of discrete ships through the beam.

4. The noise in 35 deg beam pointed at the Betty-L Barge consists predominantly of 15 Hz harmonically-related spectral lines.

5. Spectral energy below 150 Hz is strongly anisotropic in azimuth. The predominant flow of acoustic energy in this band appears to occur up the "ravine" at 325 deg. Bathymetric blockage to the east, southwest, and west appears to be taking place, although an anisotropic distribution of the noise sources themselves probably is also important.

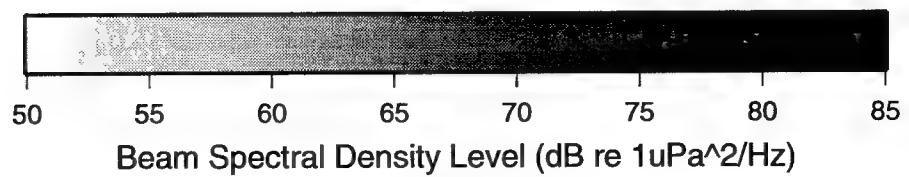
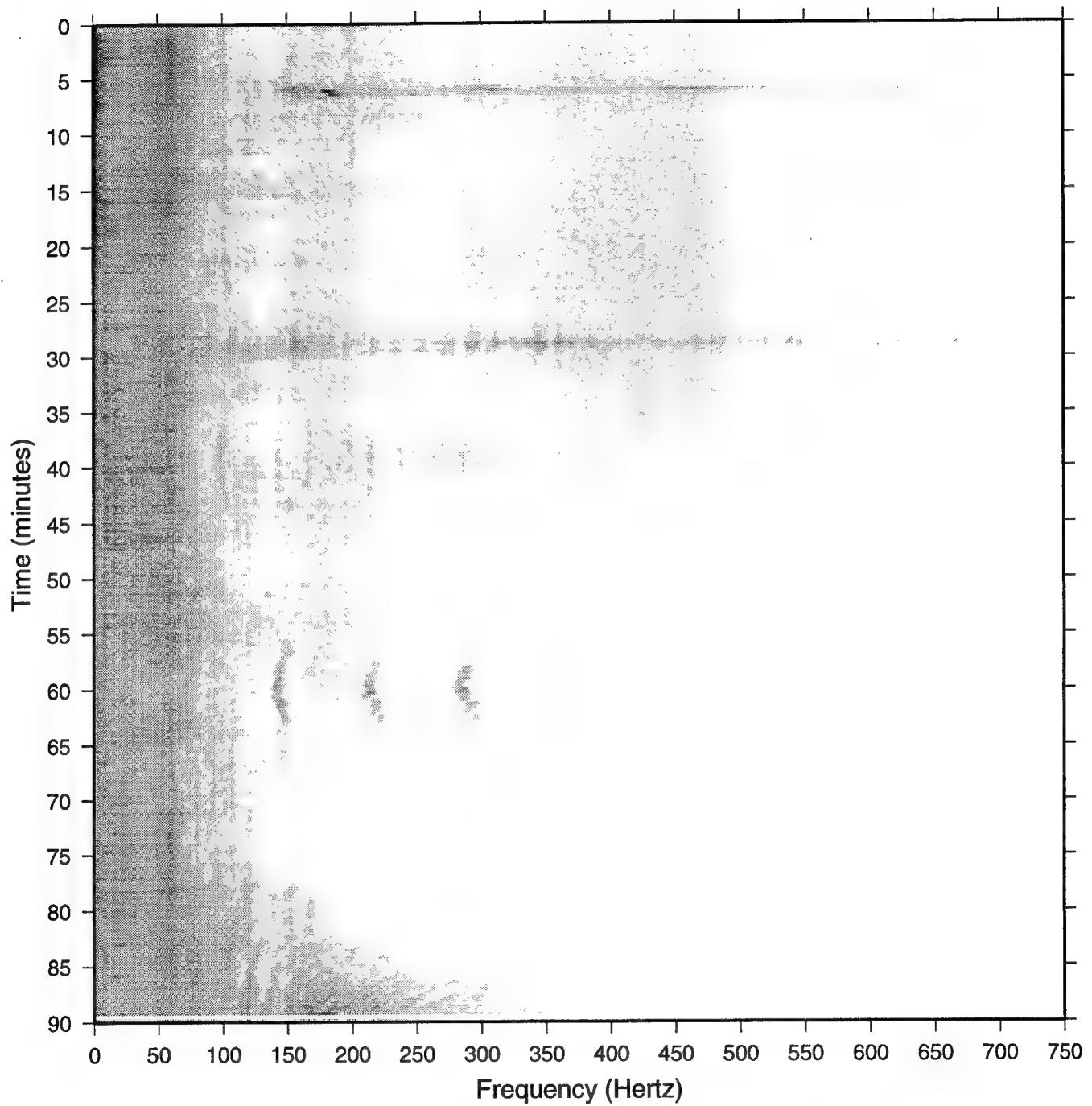
6. Spectral energy in the 150 - 225 Hz band is more isotropically distributed in azimuth and appears to decrease in level shortly after sunrise, similar to the 450/650 Hz "clouds". Therefore, this energy also may be associated with biological activity.



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

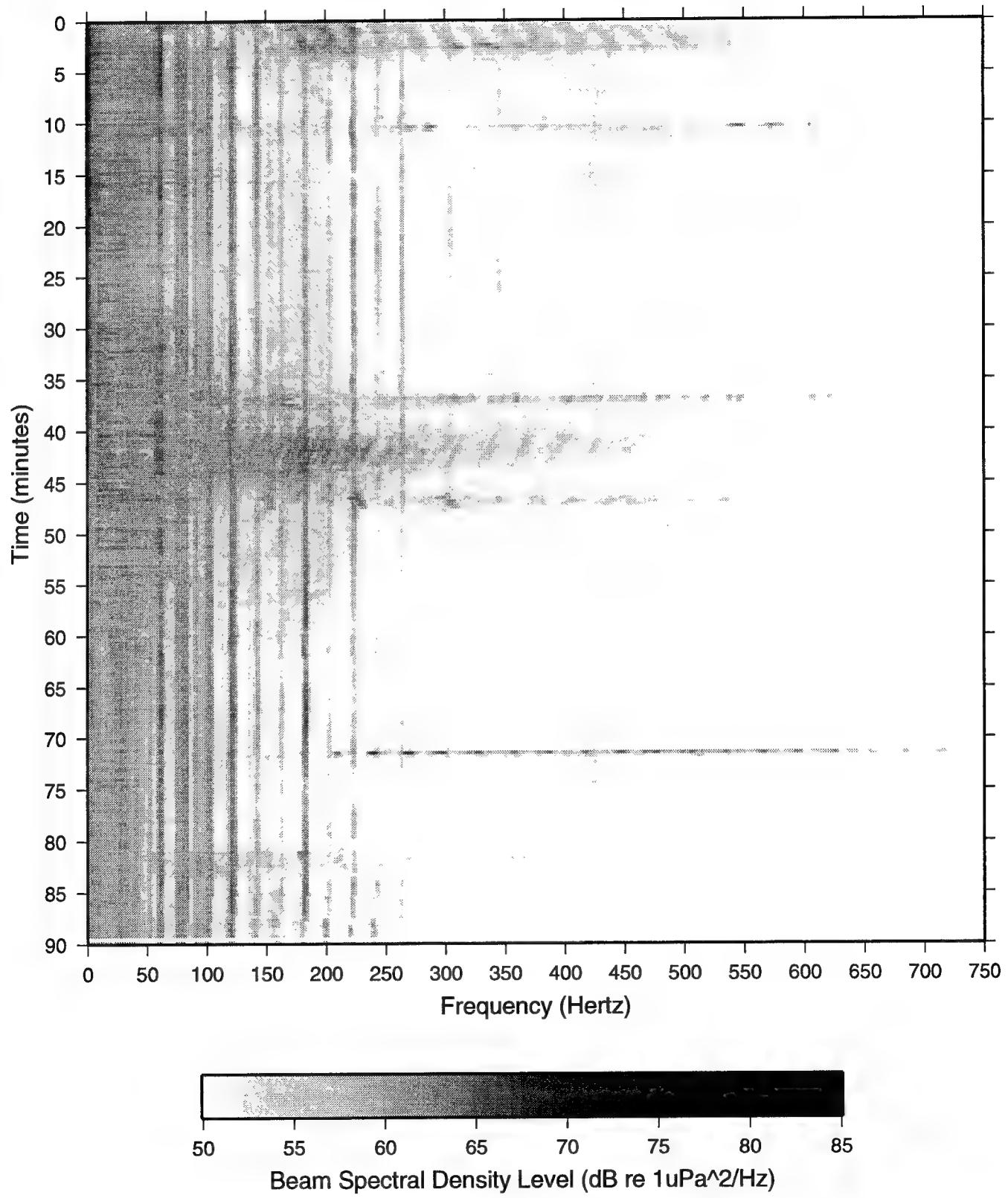
El. = 12; Az. = 0; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

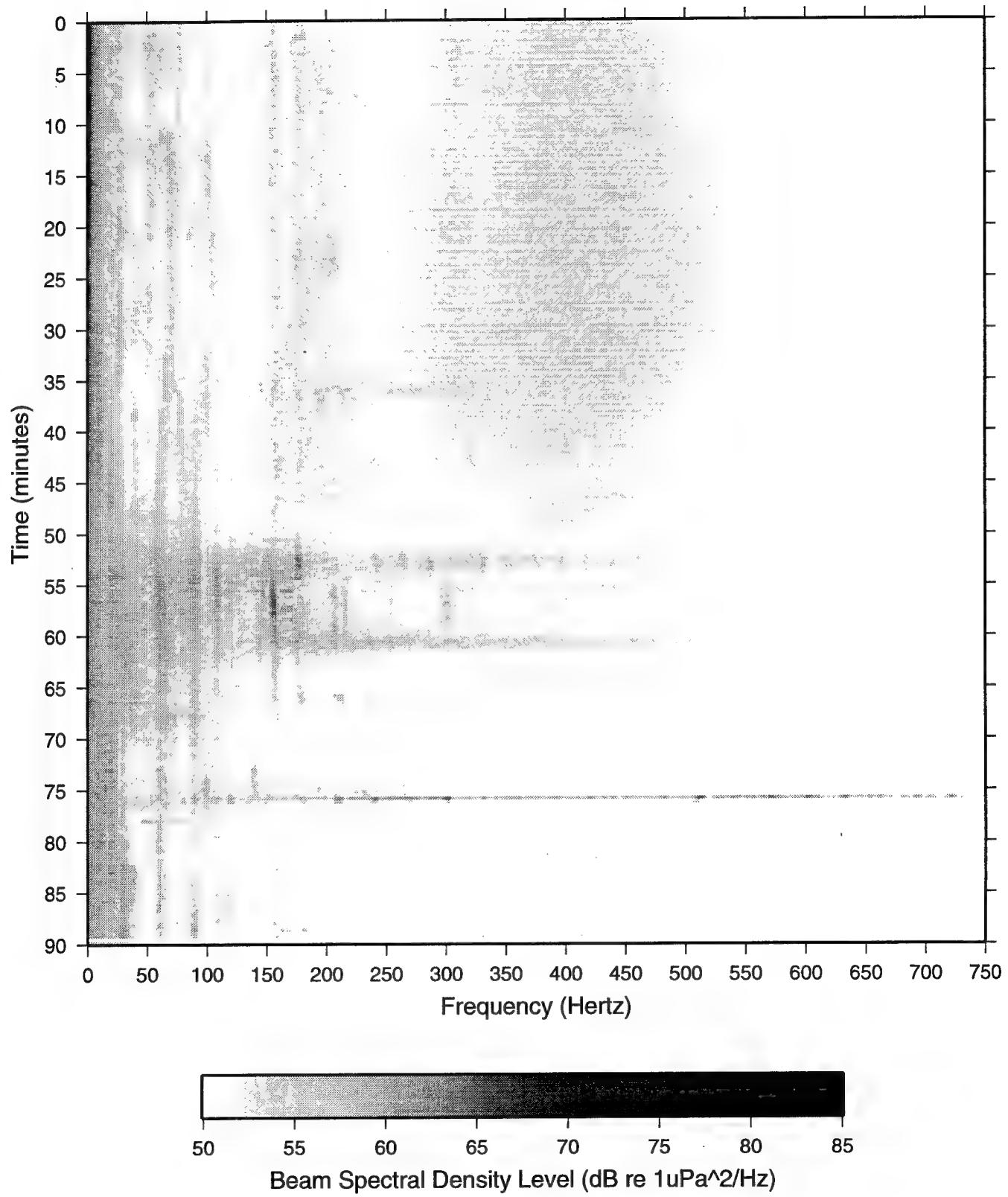
El. = 12; Az. = 35; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

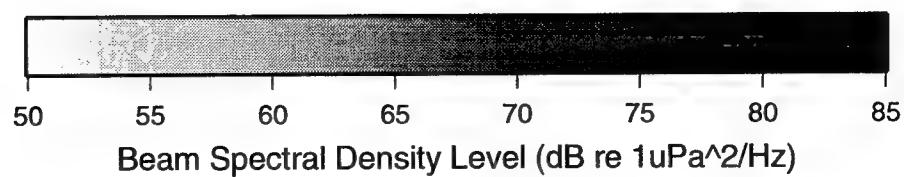
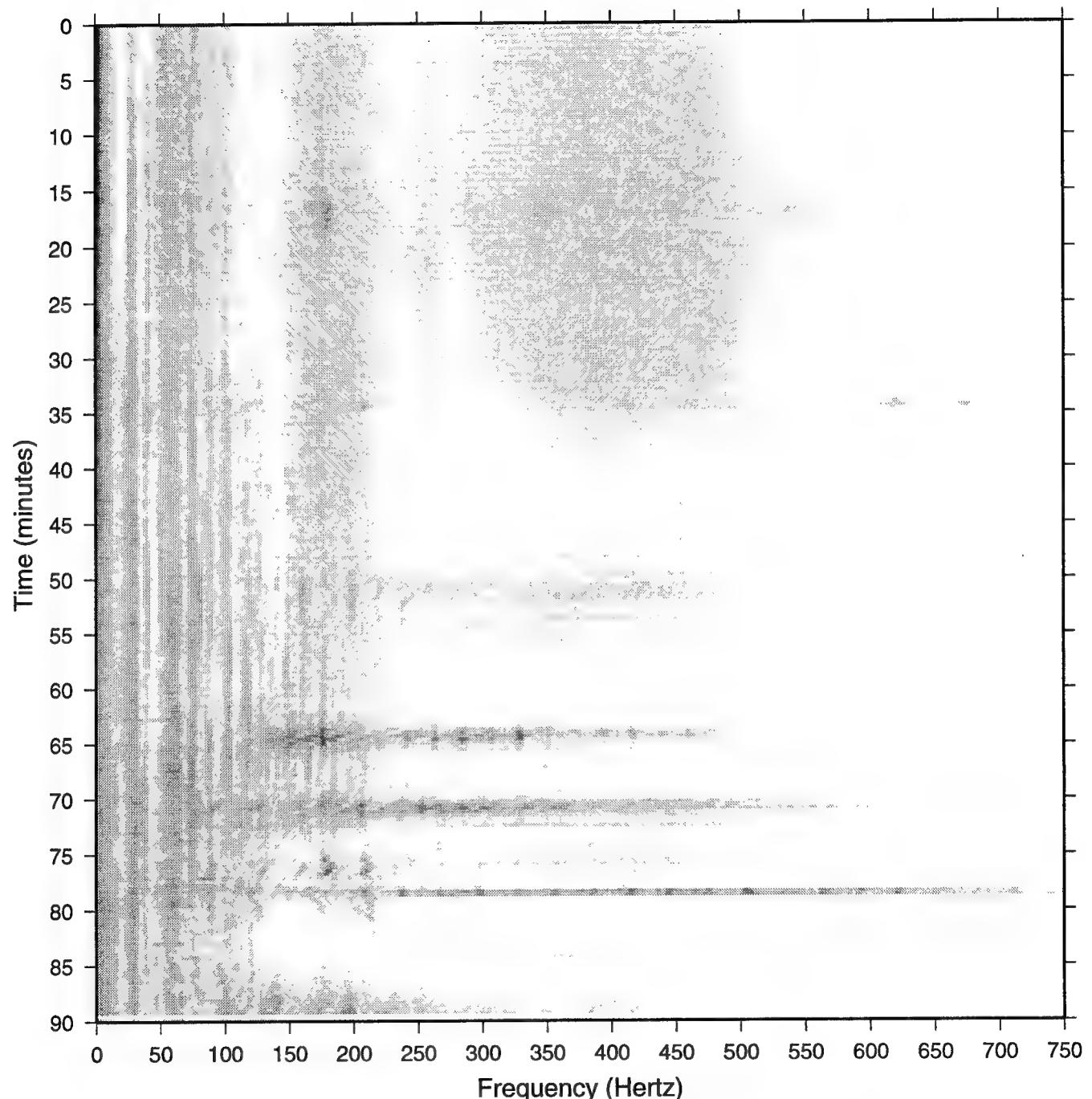
El. = 12; Az. = 79; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

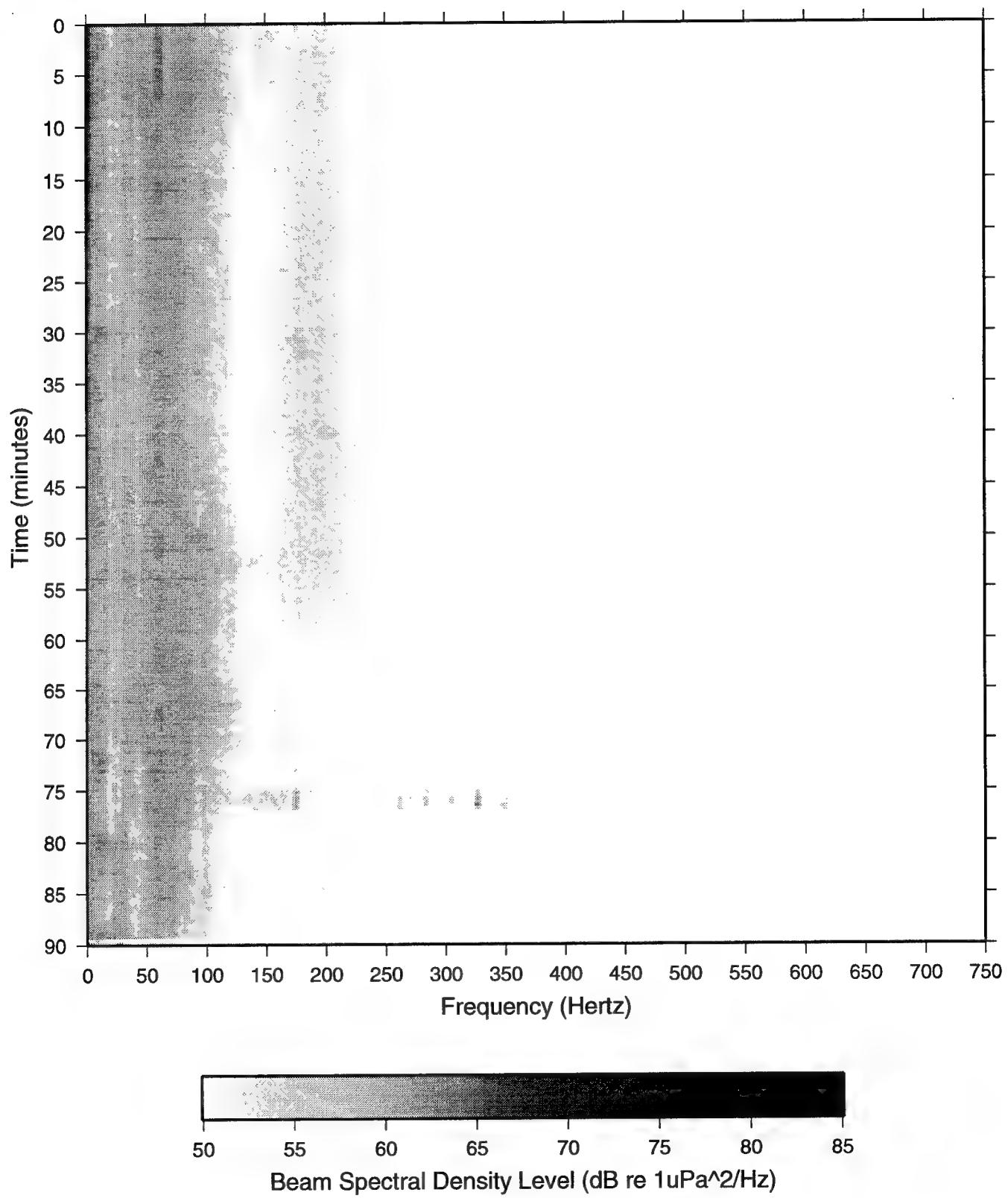
El. = 12; Az. = 120; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

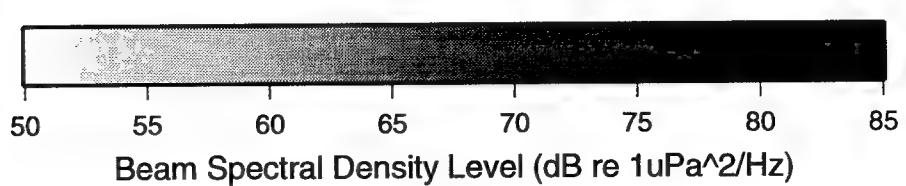
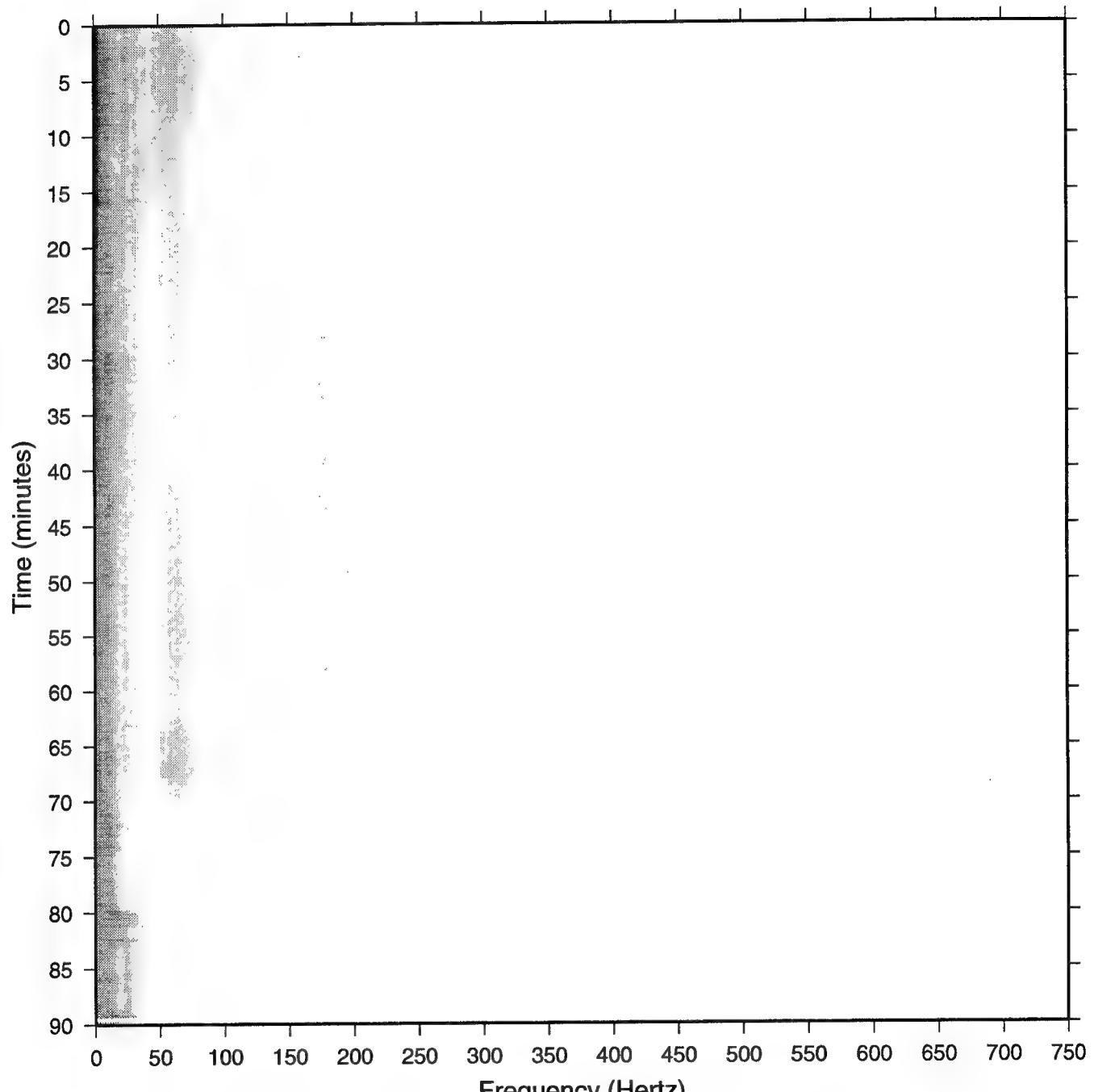
El. = 12; Az. = 180; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

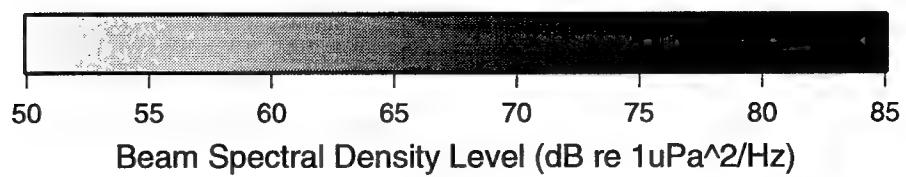
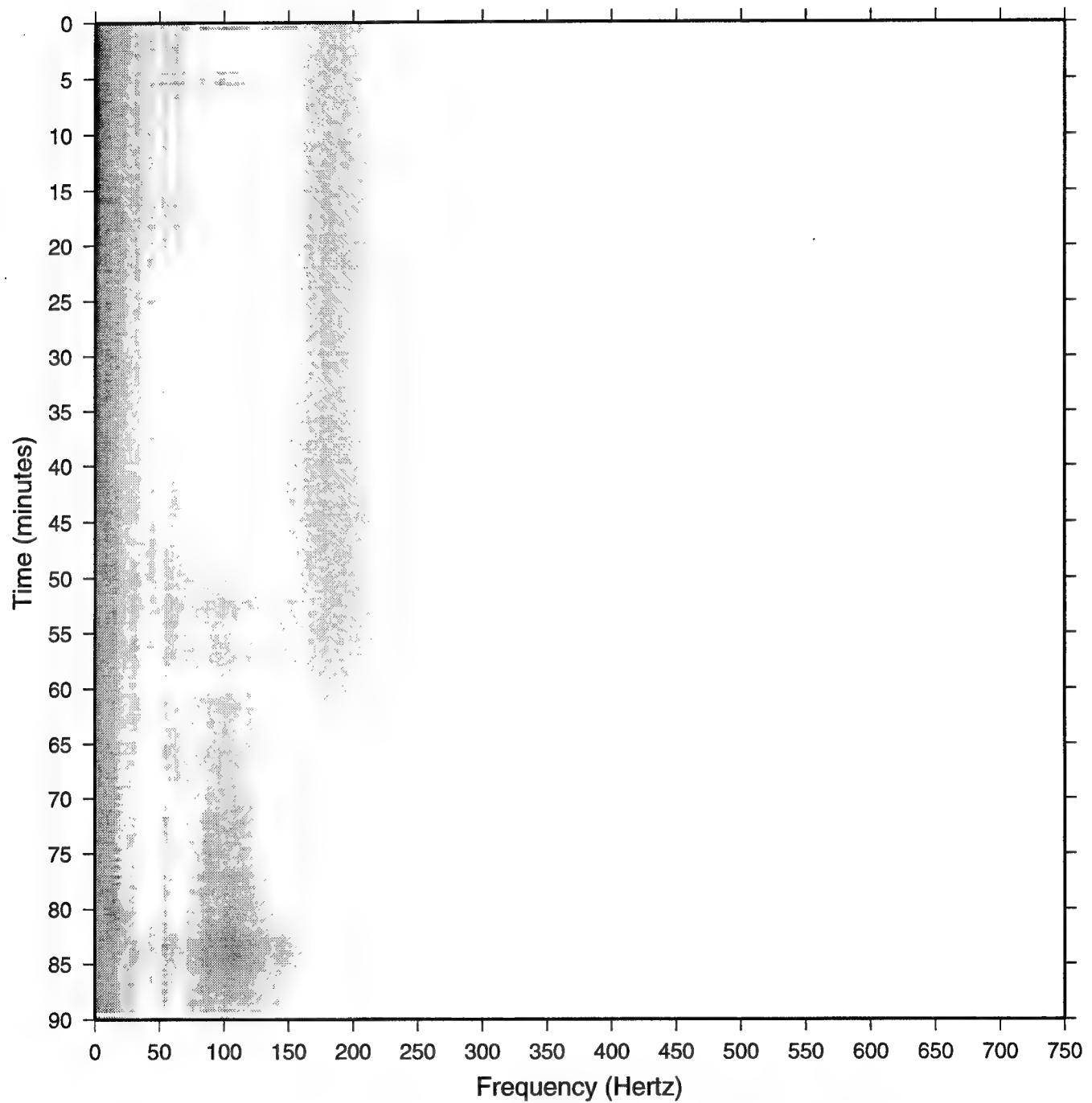
El. = 12; Az. = 219; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

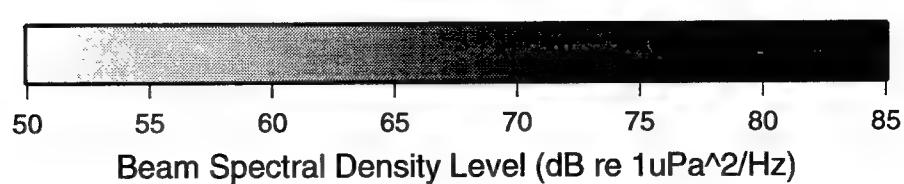
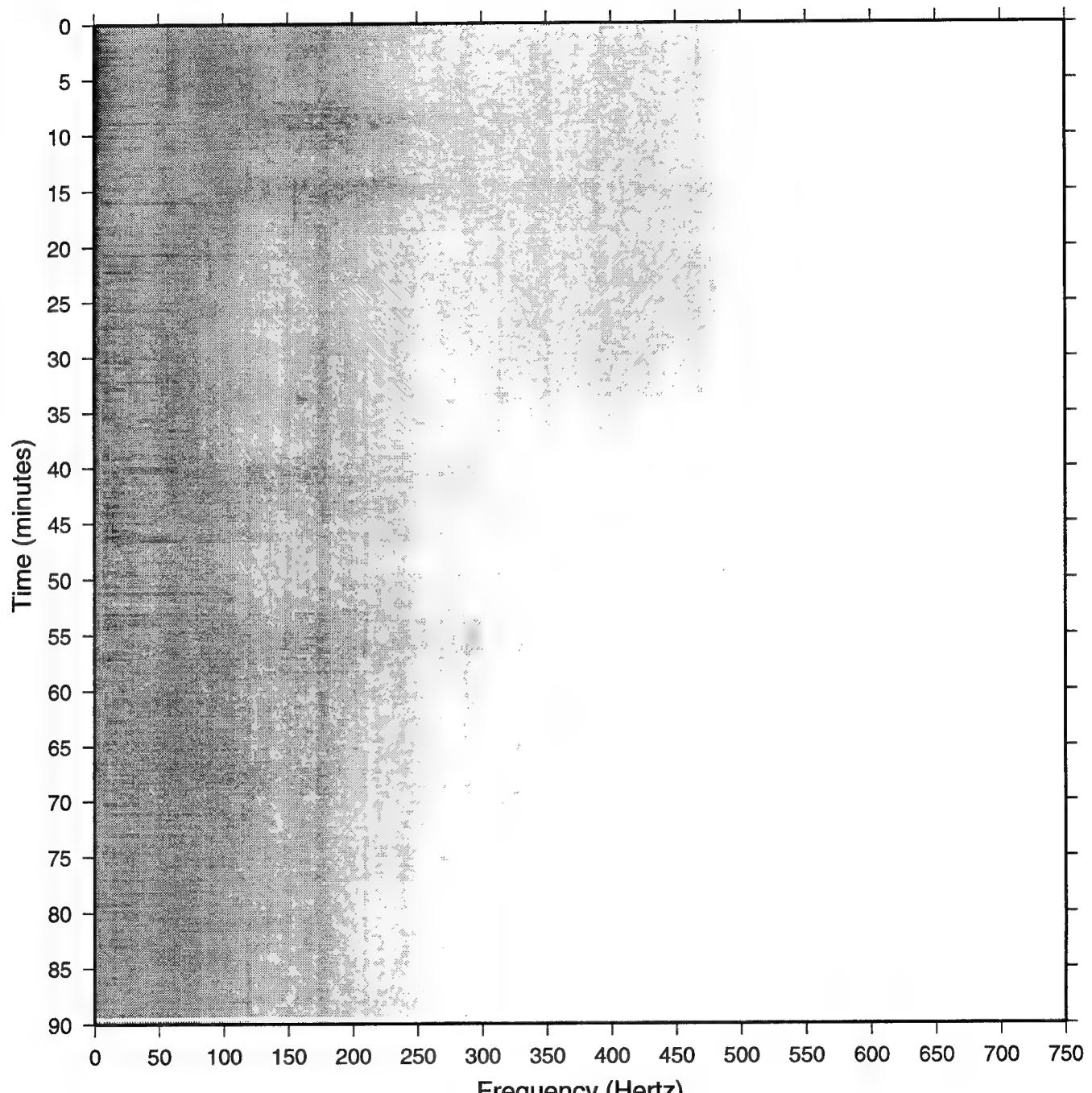
El. = 12; Az. = 259; N = 72



USTS Adaptive WNC Beamformer Response

8/17/93 05:05:00 PDT

El. = 12; Az. = 325; N = 72

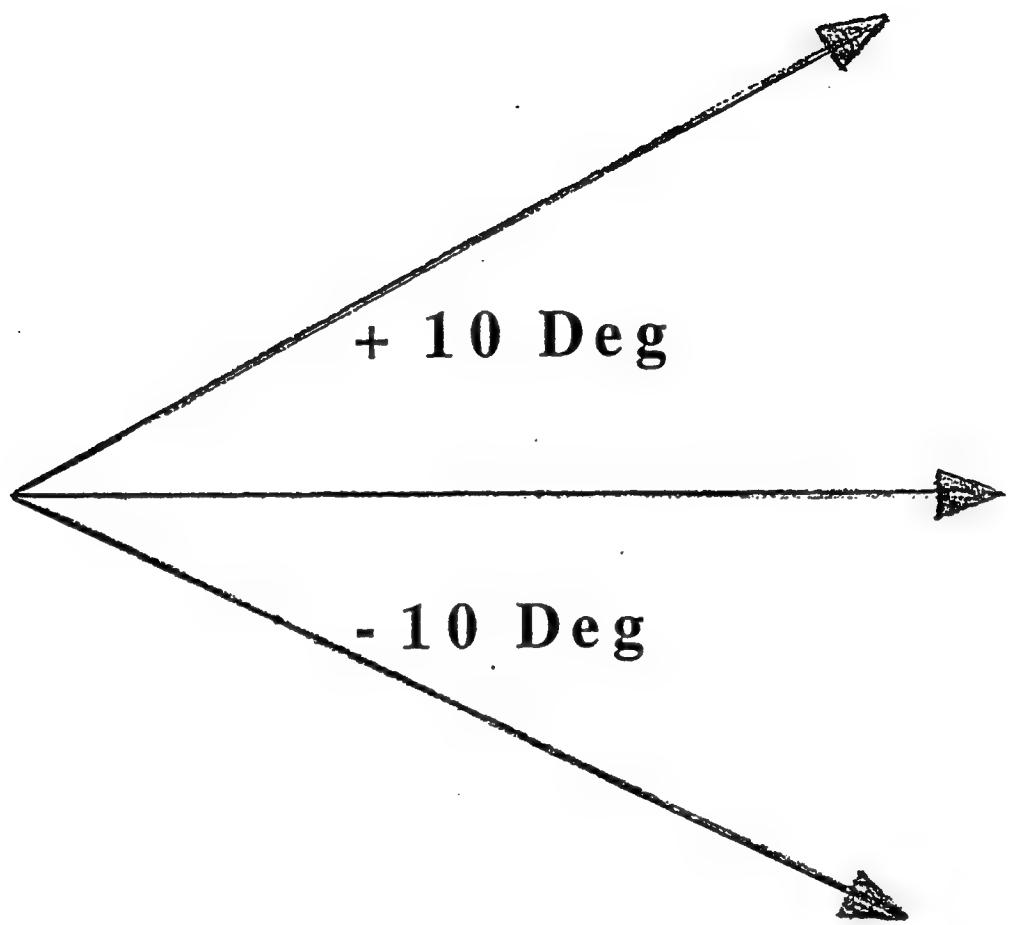


1.5 HOUR BEAM GRAMS

3 Vertical Directions

1.5 Hour Beam Grams; 3 Vertical Directions - Some Comments

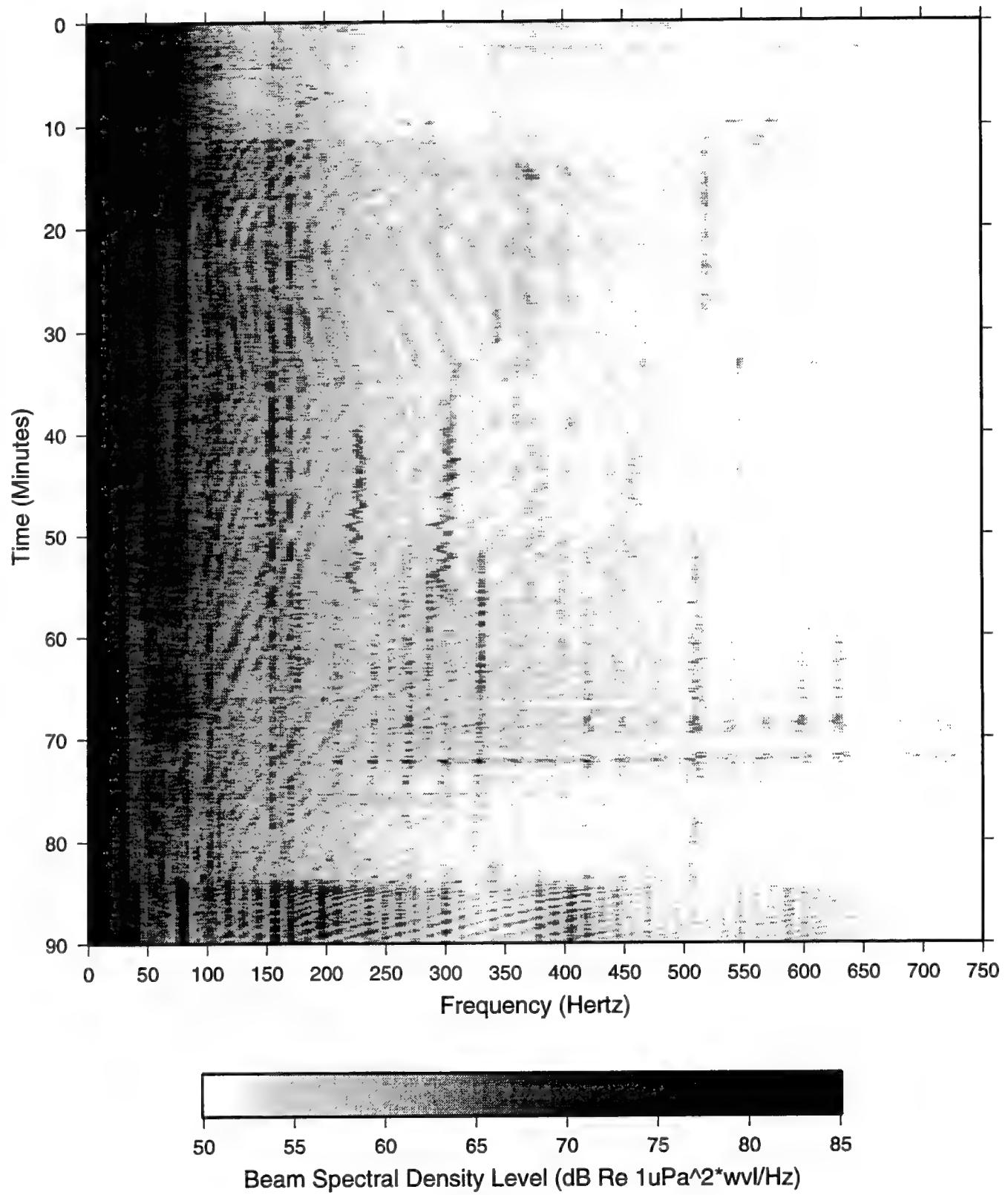
1. This 1.5 hour time period is the same period as discussed previously.
2. A vertical angle of 10 deg corresponds to the angle of arrival of an acoustic ray at the vertical array depth (the center of the array was at about 145 m) from a near-surface source at 5 m depth with a take-off in the horizontal (calculated using Snell's law and the average sound velocity profile measured near R/P FLIP during SWellEx-1).
3. Whereas adaptive beamforming methods (ABF) were used with the data from the USTS array data to determine the azimuthal distribution of acoustic energy, conventional beamforming (CBF) was used with the vertical array data because of the well-known problem of using ABF in the presence of correlated arrivals [W. D. White, 1979; A. Cantoni and L. C. Gondara, 1980]. With CBF, the main lobe width increases with decreasing frequency. Also, since the vertical array has an equal spacing between its 48 elements, its data can suffer from spatial aliasing above 400 Hz.
4. The +10 and -10 deg beam grams show nearly identical features, although the levels in the -10 deg beam are generally lower.
5. The 450/650 Hz "clouds" of biologically-generated energy are predominant features on the horizontal beam gram, but are not visible on the +10/-10 deg grams.



SRP Vertical Beam Gram

JD 229 Time 05:05 PDT

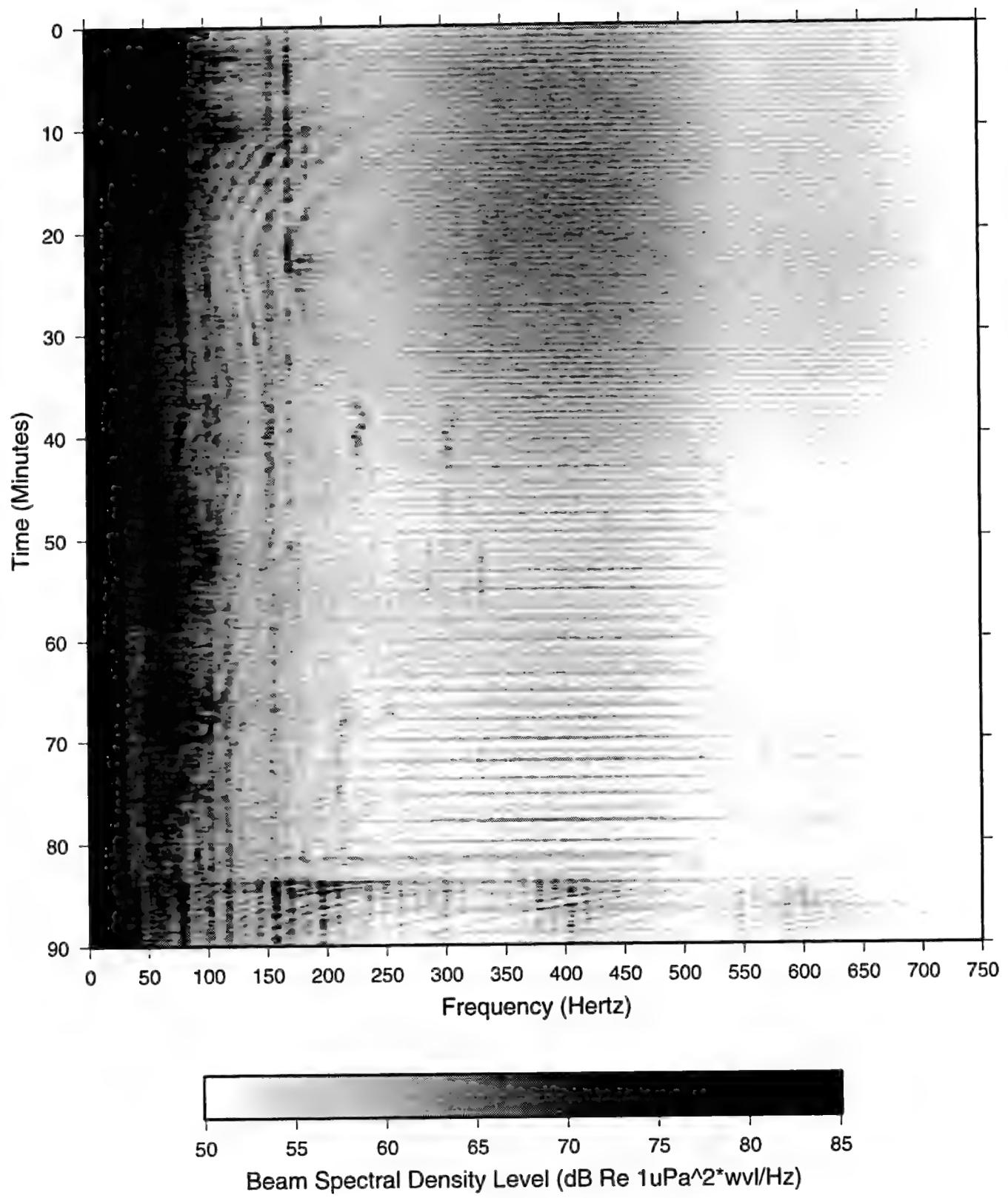
Vertical Angle = 10 Degrees



SRP Vertical Beam Gram

JD 229 Time 05:05 PDT

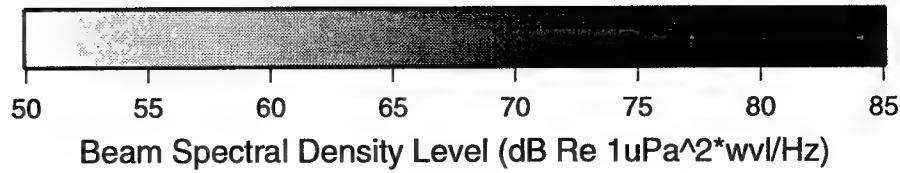
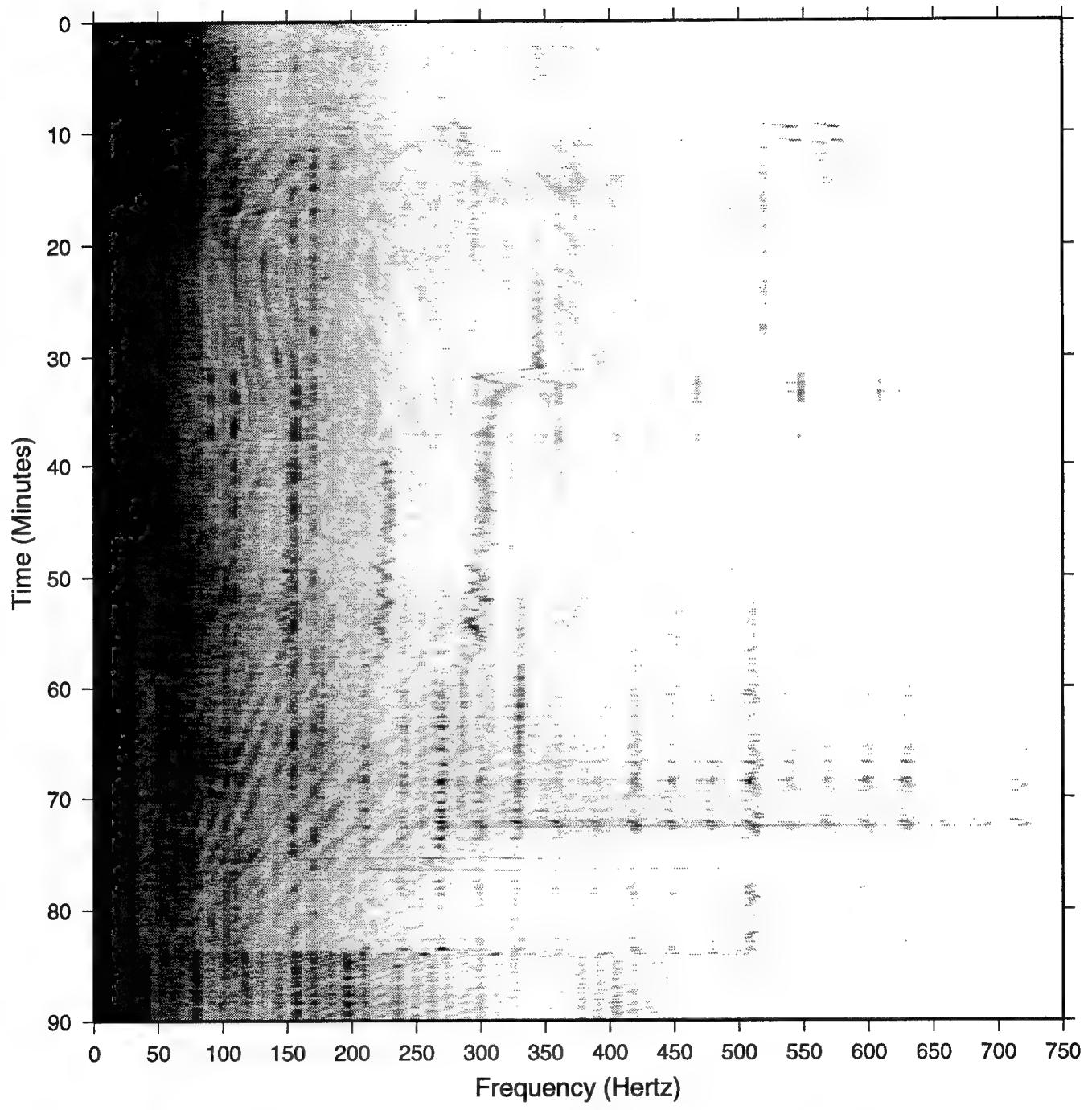
Vertical Angle = 0 Degrees



SRP Vertical Beam Gram

JD 229 Time 05:05 PDT

Vertical Angle = -10 Degrees



LARGE SHIP
(45 Minutes)

Single Element Gram

Vertical Directionality
@ 370 Hz

Horizontal Directionality
@ 370 Hz

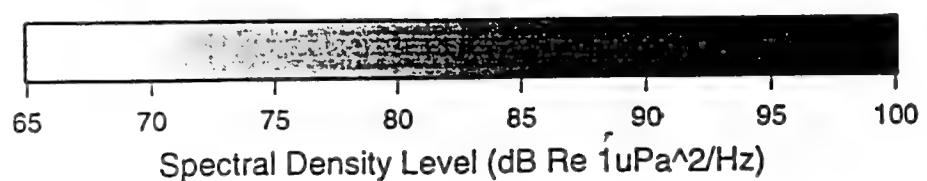
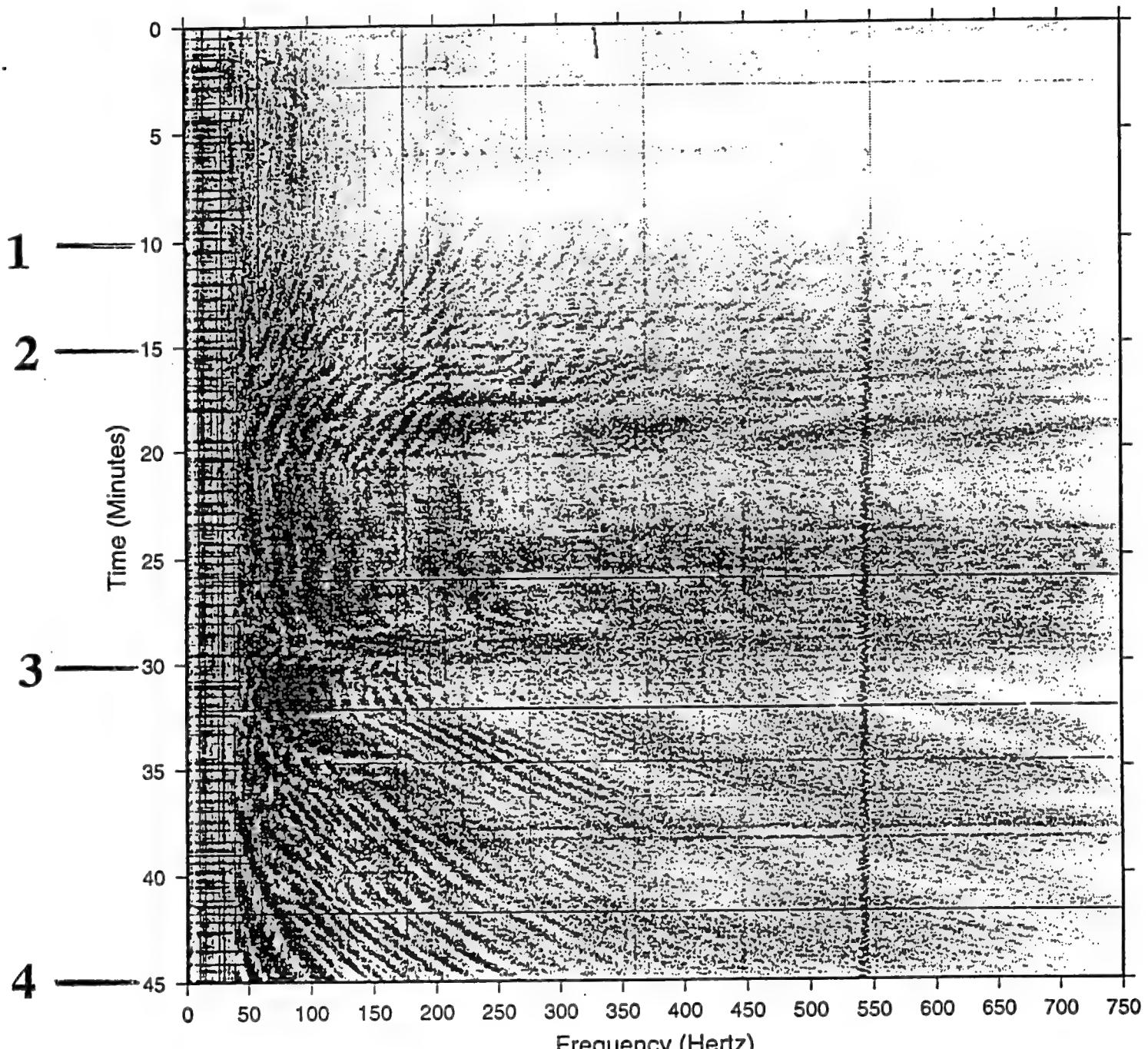
Large Ship - Some Comments

1. The last five plots refer to a 45-minute period of time, from 11:15 - 12:00 PDT.
2. The towed source was broadcasting tones at 70, 95, 145, 195, 275, 370, and 550 Hz during this whole period. These signals are seen clearly in the first 10 min of the single-element gram. However, at about 10 min after the start of the data, the time marked by the number "1", the broadband spectral levels suddenly increase by up to 10 dB. Concurrent with this jump is the sudden appearance of spectral energy between 540 - 545 Hz.
3. The vertical directionality at 370 Hz, one of the tones being generated by the towed source, also shows a distinct change in arrival structure at this same time.
4. The azimuthal directionality at 370 Hz indicates that about 10 min after the start of the data, a discrete source to the west, southwest begins to appear. It becomes progressively louder as it passes to the south of the array and heads off to the southeast and east. During this time, the towed source was located 79 deg from FLIP, transiting between stations "D" and "E" along the upslope "A <-> E" track (refer to the map following the azimuthal directionality plot; FLIP's position was at station "F"). The arrival of the 370 Hz energy from the towed source at 79 deg is clearly seen in the azimuthal directionality plot.
5. A set of five range-and-bearing fixes on a large ship were listed in the log of radar observations kept on board R/P FLIP during SWellEx-1. The fixes indicate that the ship was traveling in a straight line at a constant speed of about 10 kn. The track derived from these fixes is shown on the map as the bold, solid arrow pointing in the southeast direction, parallel to the U.S./Mexican border. The four times, indicated by the numbers "1", "2", "3", and "4", correspond to the four identically-labeled times on the single-element gram.
6. The bottom bathymetry along straight lines connecting the position of the large ship at the four indicated times and R/P FLIP are shown in the final plot (FLIP is located at range zero). The explanation for the sudden onset of the ship-generated signals is that, at position "1", the acoustic energy generated by the ship is bathymetrically blocked by the Coronado Bank. Once the ship approaches over the top of the bank and its downward-refracted acoustic emissions can then "skip" off the ocean bottom rather than penetrating into it, it becomes clearly audible at the arrays.
7. The conclusion from this set of five plots is that the temporal evolution of the ambient noise field, in single-element spectra and in horizontal and vertical directionality, is determined not only by the temporal properties of the source time functions themselves, but also by the bottom bathymetric features surrounding the measurement site.
8. Rather than viewing these surface-ship-generated signals just as interfering noise, they can also be used as signals of opportunity to empirically "calibrate" the propagation characteristics of the ocean medium about the study site.

SRP Single Element Gram

JD 229 Time 11:15 PDT

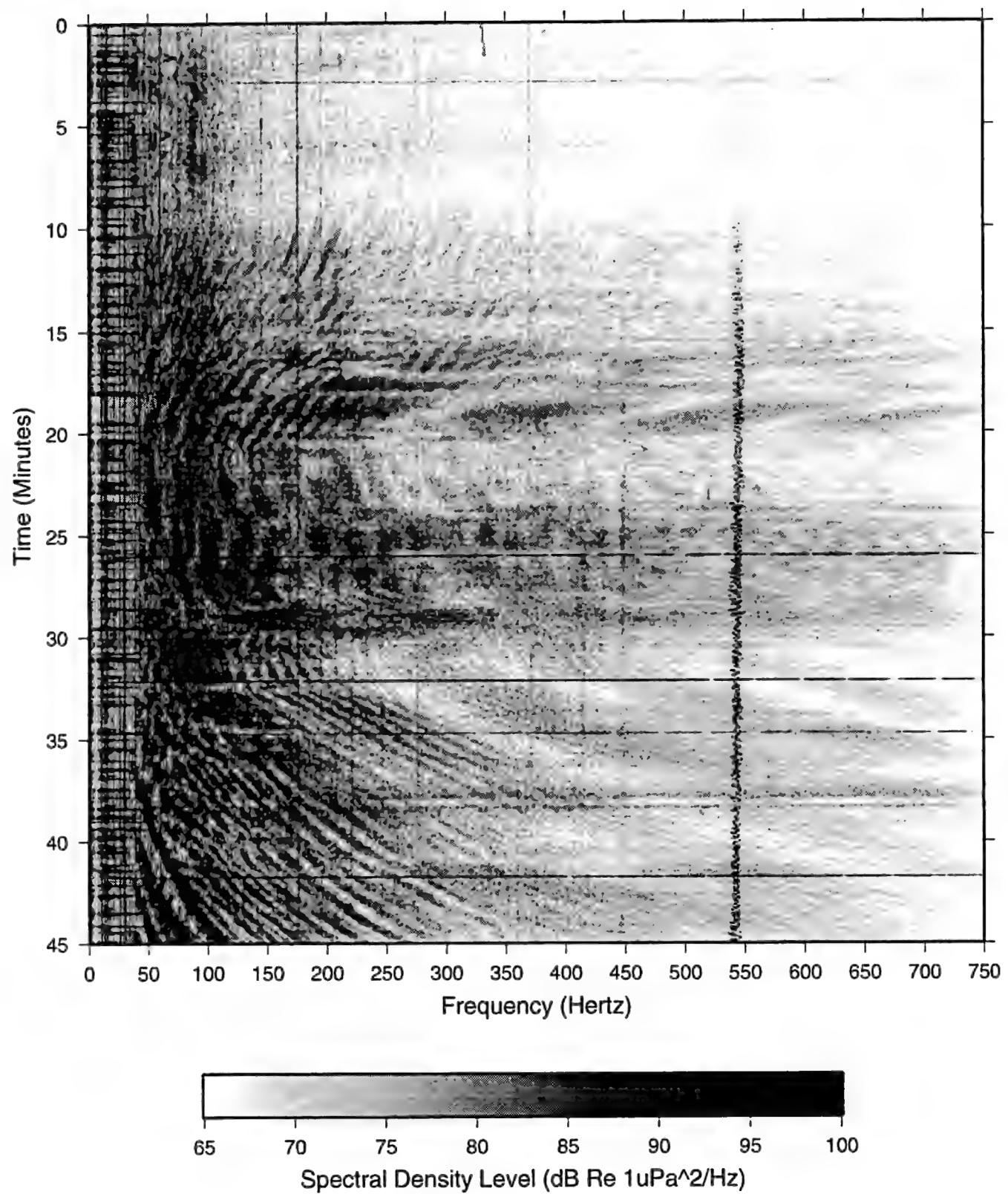
Element 8



SRP Single Element Gram

JD 229 Time 11:15 PDT

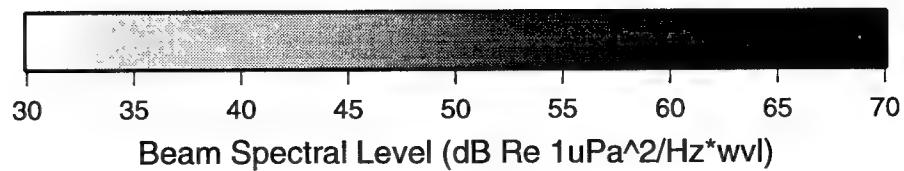
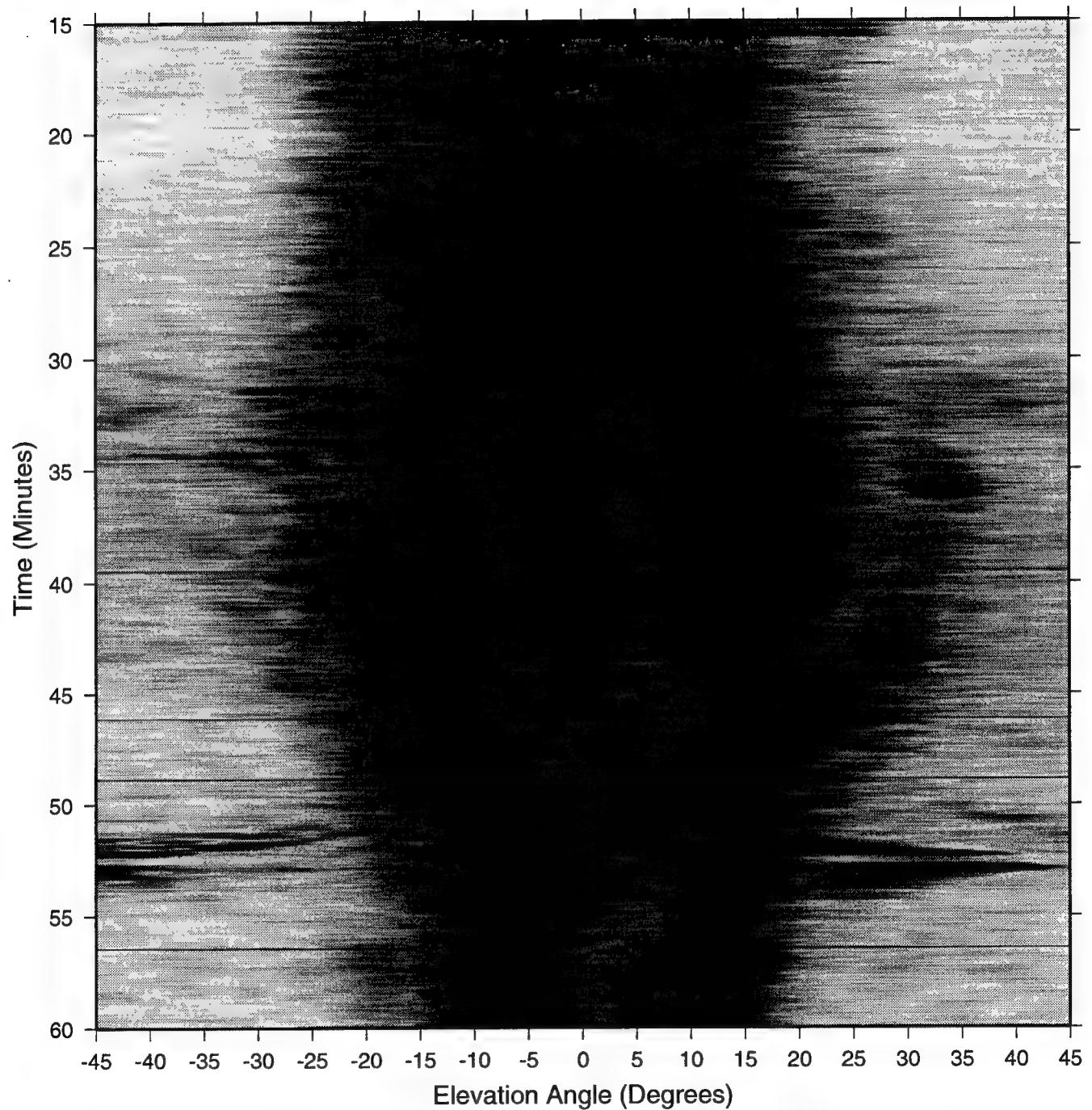
Element 8



SRP Beamformer Response

JD 229 Time 11:15 PDT

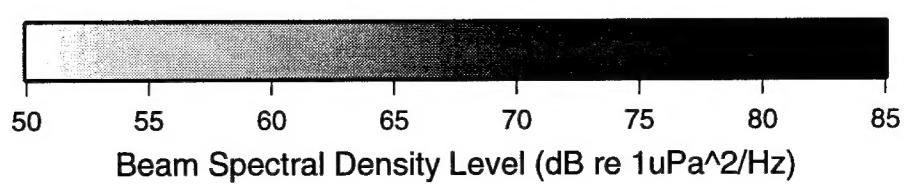
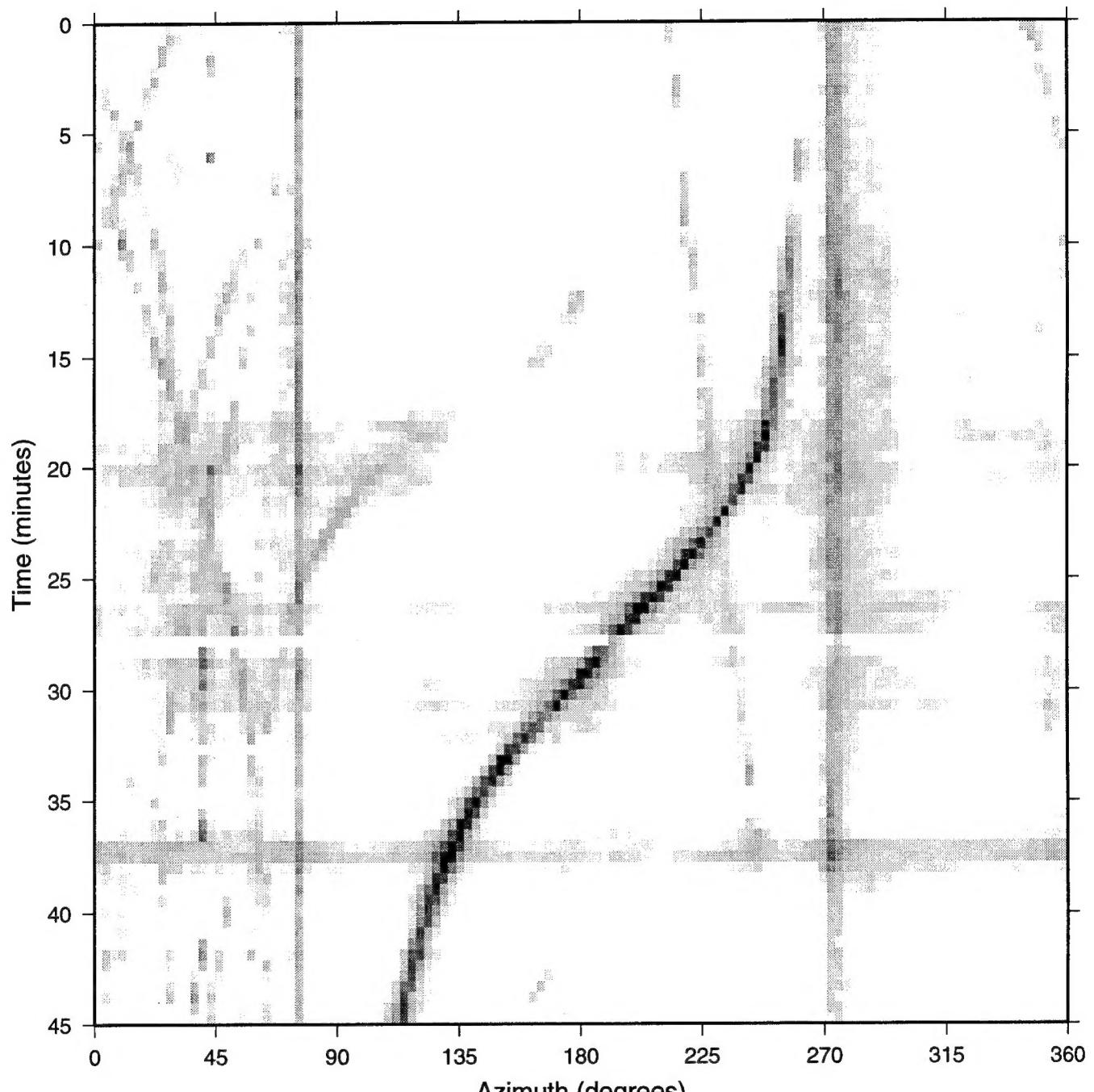
Frequency 370 Hz



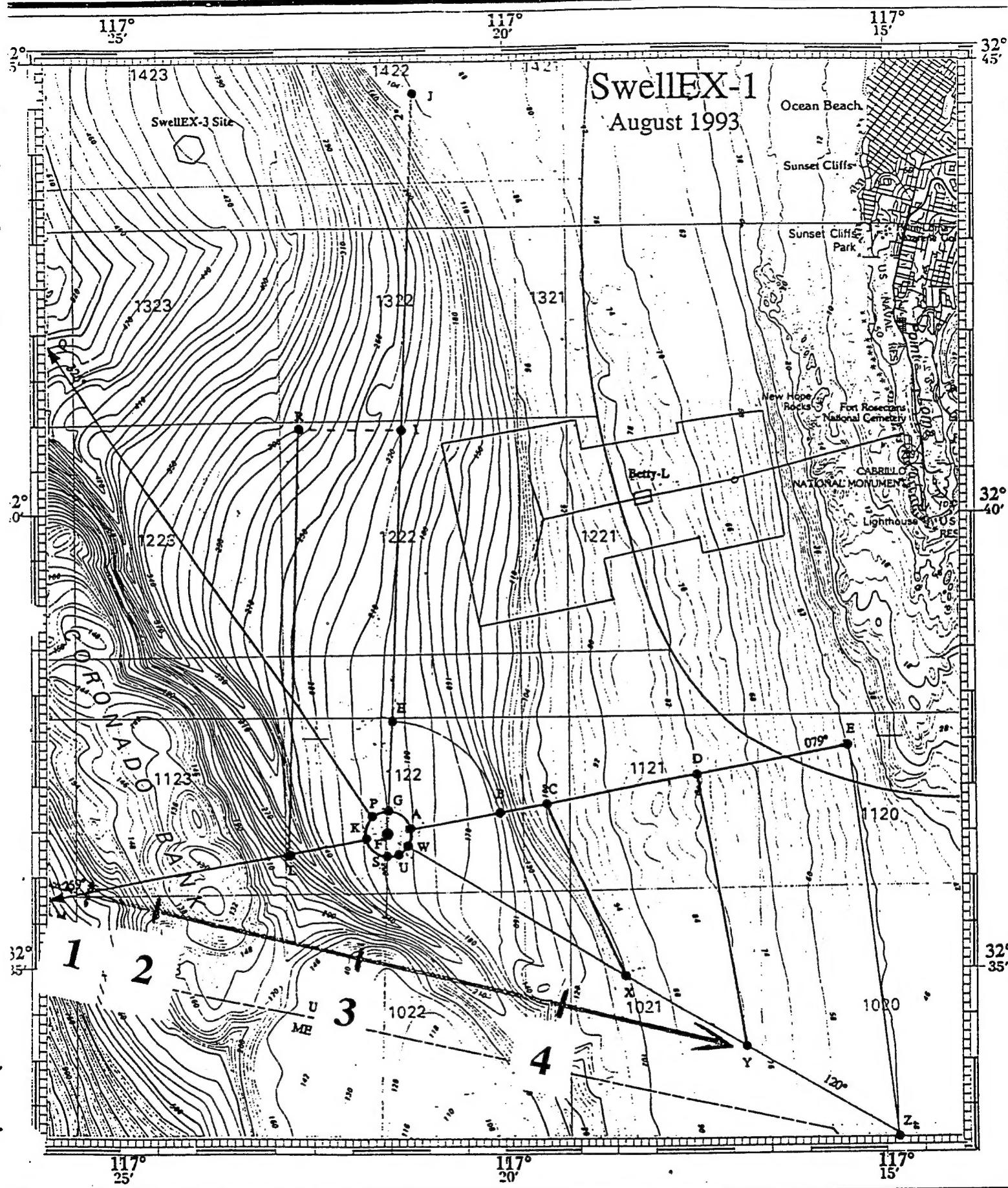
USTS Adaptive WNC Beamformer Response

8/17/93 11:15:00 PDT

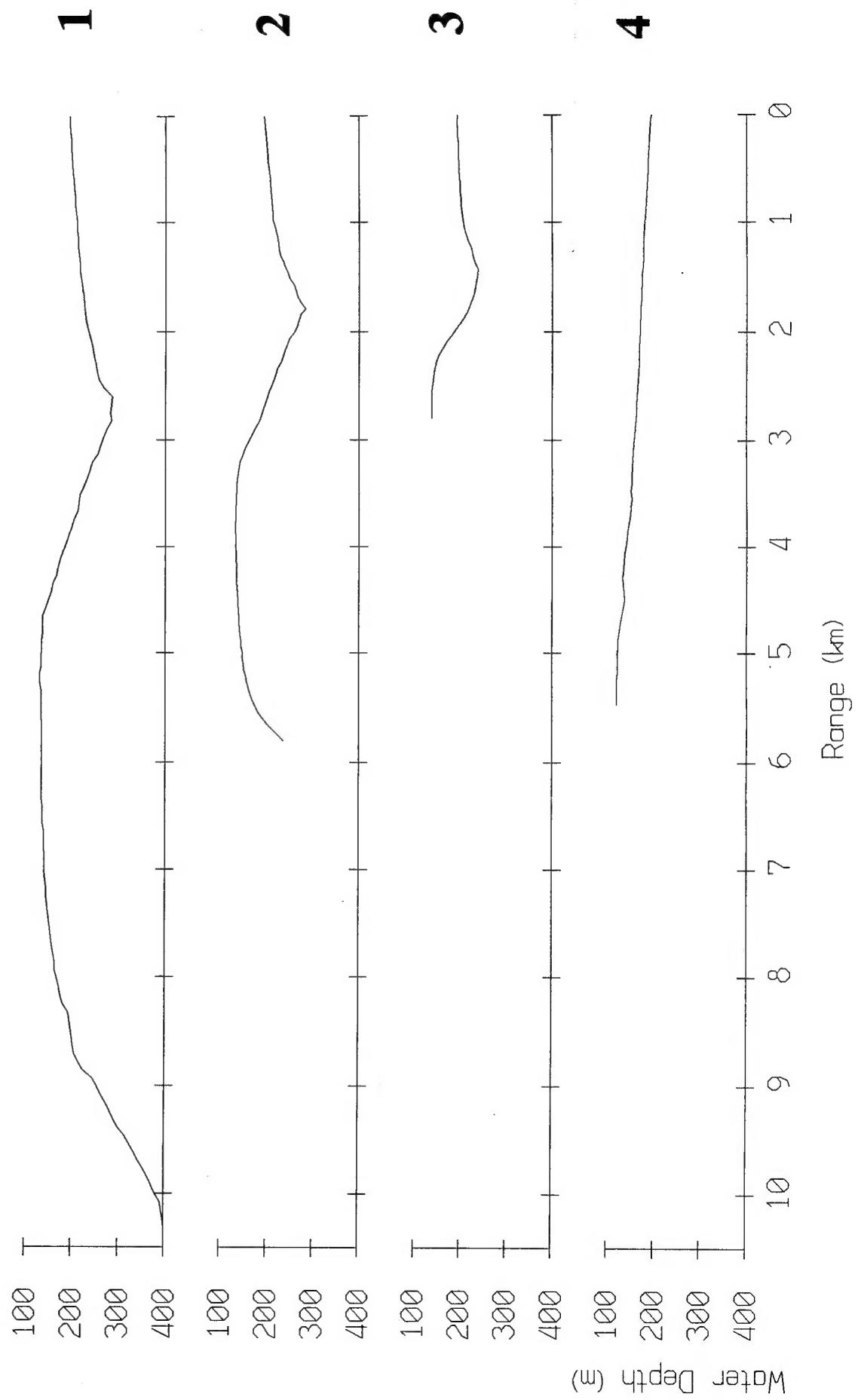
El. = 12; Narrowband Response (f=370); N = 72



SwellEX-1
August 1993



Bottom Bathymetry between Large Ship and FLIP



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